EFFECT OF TEMPERATURE ON THE STABILITY AND PRESSURE DROP OF WATER IN OIL STABLE EMULSION FLOW IN A HORIZONTAL PIPE

BY

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To the best thing that happened to me after ISLAM

MY FAMILY

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ABSTRACT

Full Name : Mozamil Mahjoub Basheer Khalid

Thesis Title : Effect of Temperature on the Stability and Pressure Drop of Water in Oil stable Emulsion Flow in a horizontal pipe

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This study investigates the influence of temperature variation on the stability and pressure drop of water in oil stable emulsion flow in a horizontal 0.4-inch I.D. pipe. Two water-in-oil (W/O) emulations of 70% water in 30% oil and 50% water in 50% oil were studied. These ratios were selected because it is used in the process of injection the acid and other chemicals in Enhanced Oil Recovery operation (i.e. water as a carrier). Water phase must be the internal phase to minimize the tubular corrosion.

The considered stable emulsions in the present study formed from two immiscible liquids, namely, local diesel, and distilled water and a surfactant commercially available as [Tallowalkylamine (ARMAC-T)] as an emulsifying agent. The external phase (diesel) was ensured all the time using conductivity prop meter. The influence of organoclay cosurfactant commercially known as (Cloisite 20A) at different concentrations in the flow was also investigated. The two emulsions considered in this study (70/30 and 50/50) were characterized by conducting the appropriate rheological studies at different temperatures using Hybrid Rheometer. The viscosities of the emulsions generated from

the Rheometer at the specific temperature were used in the pressure drop calculation. The pressure drop associated with the emulsion flow was investigated by conducting experimental measurements at different temperatures and flow rates in a horizontal pipeline. Stable emulsions were observed in all conducted experiments, and 70/30 emulsion showed more stability than 50/50 emulsion for both cases with and without organoclay. The temperature effect on the pressure drop was identified in this work. The influence of adding organoclay at different concentration was also explained. The presence of the organoclay did not show significant effects on the pressure drop at same temperature and flow rate. At the highest flow rate, the pressure drop of single phase diesel flow was very close to the stable emulsion flow.

ملخص الرسالة

الاسم الكامل: مزمل محجوب بشير خالد

عنوان الرسالة: أثر درجة الحرارة على ثبات مستحلب الماء والزيت و التغير في فقدان الضغط لسريان المستحلب في الانابيب الافقيه

التخصص: الهندسة الميكانيكية

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في هذا العمل تمت دراسة أثر تغير درجة الحرارة في استقرار مستحلب الماء داخل الزيت و تغير الفقدان في الضغط لسريان هذا المستحلب في انبوب أفقي قطره الداخلي 0.4 بوصة. تم اجراء التجارب على نوعين من هذا المستحلب: 70% ماء بداخل 30% زيت و النوع الأخر 50% ماء بداخل 50% زيت. تم اختيار هذه النسب لأنها النسب المستعملة في عمليات حقن الأحماض و الكيماويات في عمليات تعزيز استخلاص النفط. يجب أن يكون الزيت محيطا بقطرات الماء حتى يتم تجنب التآكل داخل الأنبوب. أهم تحدي في هذه العملية هو التغير في الضغط على طول الأنبوب والذي سيحد من كمية المستحلب وكذلك استقرار هذا المستحلب خلال عملية الضخ.

الغرض الأساسي من هذا البحث هو استقصاء أثر درجة الحرارة والمواد العضوية متناهية الصغر على ثبات مستحلب الماء/الزيت بالاضافة لدراسة أثر هذه العوامل على ضخ هذا المستحلب و تغير الضغط باستعمال الآتي: ديزل محلي, عامل مستحلب (ARMAC-T) و دقائق متناهية الصغر (Cloisite 20A) . كما أننا سنتعرض لدراسة أثر هذه الإضافات على خصائص وقوام المستحلب.

تم دراسة التغير في الضغط معمليا باستعمال أنبوب أفقي وأخذ القراءات عند درجات حرارة وسريان مختلف. أبانت كل المستحلبات استقرار ملحوظ إلا أن المستحلب المكون من 70% من الماء كان أكثر استقرارا من الأخر (50% ماء) مع وجود ومع عدم وجود دقائق متناهية الصغر. تم أيضا

عرض أثر درجة الحرارة على التغير في الضغط. لم تعط إضافة الدقائق متناهية الصغر تغير يلحظ في التغير في الضغط عند نفس درجة الحرارة. عند أعلى معدل للسريان لوحظ أن التغير في الضغط عند ضخ الديزل يوشك أن يكون مساويا للتغير في الضغط عند ضخ المستحلب.

CHAPTER 1

INTRODUCTION

1.1 Emulsions

Emulsion is a special type of two or more immiscible liquids where one liquid phase is dispersed inside the other phase. Emulsions are generally used in several significant oil and chemical industries such as petroleum, pharmaceutical, cosmetic, food and they also have many biomedical applications. Oil and water emulsion can be classified as: oil in water emulsion, water in oil emulsion and complex emulsion. One of the major problems in the oil industry is the transportation and the production of water–oil emulsion flow in pipes. In particular, the mixture of oil, hydrates, and gas and sea water in sub-sea oil production. The productions of many wells are combined under the water, and then a mixture of oil, water and gas is transported for may be a long distance toward onshore where it will be separated. Also, when the reservoir pressure decreases, the water must be injected to maintain the pressure inside the reservoir and it might be that the water fraction to reach 99% [1]. Actually, studies showed that the percentage of water in oil pipe can influence the power required to pump the oil and that happens because of the change in the pressure drop in the pipe.

Adding water to oil has many effects:

- When the oil is in the core (water is the external phase), the water layer around the oil will decrease the pressure drop.

- Adding water to oil will complicate the prediction of fluid flow.

- Water fraction in oil pipelines leads to formation of a carbonic acid solution, which has a corrosive nature.

Many researchers noticed that the oil emulsion got a positive effect on the oil recovery. The flooding process in the reservoir provides a good time of the interfacially active component produced from the reaction between the acidic or nonacidic component in resin, asphaltine and saturated fractions with alkali. They found that the stability of the W/O (water in oil) emulsion increases because of these interfacially active molecules. After many lab experiments, they also proposed many recovery mechanisms. They gave a hypothesis that the high pressure drop and the mobility controlled by the naturally occurring emulsions are all resulted from the naturally emulsion formation.[2]

The reduction of the salinity increases the oil recovery and that is because the electrical double layer in the aqueous phase will expand and therefore the tendency for fines will increase. The main three components of crude oil emulsion are: brine, emulsifier and the oil. Sometime the emulsifier can be treated as a part of the oil and by influencing using an external force the emulsion will form. The most common type of emulsion found in the real operations is the water in oil emulsion (which will be studied in this dissertation). The stability of the oil-water emulsion depends on many factors. Some of these factors controlling the process of forming a stable emulsion can be listed below:

- The percentage of the water to the oil.
- The salinity of the water.
- The rate of adding the water to the oil.
- The rotational speed of the mixer.

- The time of mixing.
- The volume of the emulsifier used.

There are very sensitive factors which are very important to establish the required emulsion, even the volume of the tank where the emulsion has been mixed is a factor, in addition to, the material of the tank and the wall friction factor.

1.2 Organoclays:

Organoclays are resulted by modifying quaternary amines (surfactant that contains nitrogen ion) with bentonite. The positively charged hydrophilic end (the nitrogen end in the amine), and then the ions will exchange into the clay platelet for calcium and sodium.

The bentonite is the main component of organoclay; it is a volcanic ash that consists of mineral monotmorillonite.

The dissolved hydrophilic amine end into the oil droplet results in removing that droplet from water and this is why it is used in filtering the water from oil. And also the organoclay does not foul quickly because the partition reaction takes place outside the clay particles.

The most important part to develop polymer nanocomposites is the organoclays and also it is one of the most developed areas of nanotechnologies. The researches in this part were started in 1920s after the discovery of the X-ray diffraction in 1913.

There are many applications of organoclays such as:

- Rheological control agents.
- Grease.
- Paints.

- Adsorbents.
- Cosmetics.
- Personal care products.
- Oil well drilling fluids.

Organophilic clays are used for removing oil and grease from water and this action can reduce the cost that can be consumed in the operation process. It can also be used in ground water cleanup at underground storage tank sites, old disposal sites and also in the treatment of landfill leachates.

Recent investigations revealed the effect of using the organoclays to decrease the pressure drop when pumping emulsions in pipes. The primarily results showed that adding organoclays to an emulsion will reduce the emulsion viscosity and hence the friction factor[3]. Also, researchers seek to use the organoclays as an emulsified agent. It seems to be efficient if that happen because of the cheap price of the organoclays compared to any other emulsifier.

1.3 Objectives

The main objective of the present work is to investigate the effects of temperature and organoclays on the stability and pressure drop of water in oil emulsion flow by using the following:

- Oil type: Diesel;
- Emulsifier/surfactant: Hydrogenated tallo walkyl Amine acetates (ARMAC-T);
- Organoclay coemulsifier: Cloisite 20A.

The structures of the afore-said emulsifier and coemulsifier are given below.

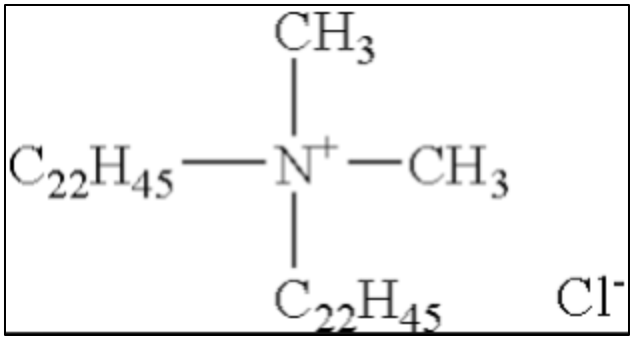


Figure 1-1: Emulsifier (Hydrogenated tallowalkyl Amine acetates-ARMAC-T)

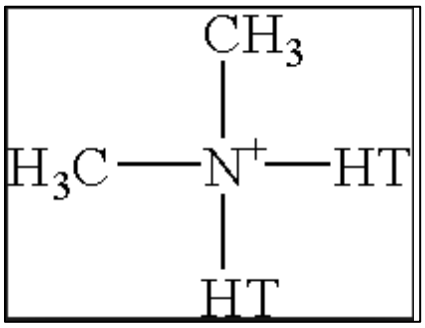


Figure 1-2: Coemulsifier (Dimethyl, dihydrogenatedtallow, Quaternary ammonium-Cloisite 20A)

Where the T in HT, refers to Tallow (~65% C18; ~30% C16; ~5% C14)**.**

The organoclay coemulsifier is anticipated to combat the adverse phase inversion due to temperature. The proposed W/O emulsions will be characterized by conducting the appropriate rheological studies using Hybrid Rheometer.

1.4 Thesis map

This thesis is divided into five chapters. The introductory part is given in **chapter one** and the remaining chapters can be described as follows:

Chapter two: Presents the literature part by giving an overview of the research that have been conducted to study the influence of the temperature on the stability and pressure drop of water/oil emulsion.

Chapter three: This chapter explains the whole experimental setup and the procedures that used to conduct the experiments.

Chapters four and five: The experimental results are presented in chapter 4 with detailed analysis and discussions. Based on our findings, a conclusion is presented in chapter five.

CHAPTER 2

LITERATURE REVIEW

An emulsion is defined as two different liquids in which the droplet of one of them encapsulated inside the other phase. There are two types of emulsions: the first is water in oil (W/O), and the second is oil in water (O/W). There are many applications in emulsions such as in cosmetics, paints, asphalt, food and hydraulic fluid.

In this review, relevant studies done in different applications of emulsion classifications under some related topics will be reviewed:

2.1 Emulsion stability

The study of the transportation of heavy crude oil emulsions showed that adding anionic surfactant to the oil in water emulsion increases its stability with the increase of surfactant concentration and with a decrease in the interfacial tension of the crude oil-water. It was found that in the aqueous phase the maximum electrolyte concentration was 1M (molar concentration) at a concentration of surfactant of 0.5% in the aqueous phase on the other hand, no emulsion appears when the concentration of an electrolyte was less than 1M. By increasing the temperature and the mixing speed and increasing the oil content, it was found that the viscosity of the Geisum crude oil in water was decreased. For pumping and production of heavy crude oil, the surfactants can be injected into the well bore. Also the most suitable demulsifiers after transportation was determined, using Alkyl phenol formaldehyde ethoxylated-propoxylated as a demulsifies at 50℃ and 60 ppm dose was very efficient to resolve the emulsion [6]. In practice, transporting a heavy

crude oil is a serious problem in long distance applications. Many researchers worked and attempted to solve this problem. The effect of temperature was studied and it was found that for high flow rates the transportation can be done at a low temperature in contrary for the low flow rates. It was also found that the temperature of the emulsion has a strong effect on the viscosity. Furthermore, they found that there is a critical temperature where the properties of the emulsion will breakdown under the transport condition of a specific pipeline. Using OP-10 (10 mg of oxycodone) as an emulsifier which was found to result in the best emulsion stability for J7 crude oil because of its properties that will reduce the viscosity of the crude oil for economical transportation [7].

2.2 Effect of emulsion measurements device

Researchers studied the viscous effect on the emulsion stability measurements. The main aim of that study is that to try to predict the flow of the very viscous crude oil in the industry coalesce and laboratory setup and build a model for both so that more results can be obtained to predict and improve the performance of the industrial processes. The model they obtained showed good results for the viscous crude oil. They studied the electrocoalescers performance and found that the theory of simple electrostatic can explain the separation phenomena when they decreased the coalescence resistance by using an efficient demulsifier [8]. The investigations of ways and technics for stability continued, searching leads to that the emulsifying agent is necessary for the stability of any emulsion. They found that using 5% NaCl concentration would provide 100% stable emulsion. They did not stop at that point they said that even the impeller type can affect the stability. It was found that the S-curved blade gives a stable emulsion for two days and more [9]. Using nanoparticles in dilute emulsion to get a stable mixture has several

applications. The major common use of these nanoparticles is in highly concentrated emulsions. Hydrophilic and hydrophobic particles are types of nanoparticles used for high concentrated emulsions. The studies showed that high hydrophobicity tends the aqueous phase or oil phase separated and the tendency of forming an emulsion will minimize. Using an emulsifier such as SMO (Sorbitan MonoOleate) tend to create a stable emulsion under shear but not long term stability in the condition of highly concentrated or overcooled emulsions. Using SMO with the best silica with a good degree of hydrophobicity in an emulsion gives a good result of stability [10].

2.3 The emulsion effect on measurement devices

Many scientists studied the effect of sudden expansion and contraction in the frictional pressure loss. They found that the emulsion type and its concentration do not affect the loss coefficient (K, in the formula $h_f = K\ V^2/2$). Also, they found that using the single-phase Newtonian flow equation for calculating the pressure loss in two phase oil/water mixture can give an agreement results and the loss coefficient is independent of the concentration and the type of emulsion [11]. The accuracy of the flow rate measuring devices was also studied. For large volume of emulsions, wedge meters and segmental orifice have been studied, these two instruments shows an accurate results [12].

2.4 The Change in droplet size

Hofman and his team [13] studied the emulsion differences between decane + $CClR_4R$ in water using Na Aerosol OT and Na oleate as stabilizers and the electrostatic repulsion difference as long as spherical droplets are considered alone. The electrostatic repulsion will be clear when the interfacial tension is lower than 0.1 mN/m. They found that Na oleate gives more stability than AOT (Aerosol OT) emulsions for low coagulation. Also,

they found that the AOT stabilized emulsions show a gradual mode in the transition from rapid to slow coagulation [13].

By controlling the characteristics of silicone perfluoro polyethoxymethoxy difluorohydroxy ethyl ether (PFPE–OH) and fluorosurfactant, silicon-in fluorocarbon-in-water(S/F/W) double emulsion could be prepared. The major substance that affects the droplet size and the stability of the double emulsion is PFPE-OH. The optimum way to form this double emulsion in stable way is by making the silicon in the inner part and the fluorocarbon as a shell part and to enhance stability fluorosurfactant should be used. The resultant double emulsion will be more stable in high temperatures which will make it very efficient in the cosmetic industry [14].

The droplet size selection and the nematic thermotropic emulsion were studied by dispersing a crystal liquid in water for many materials and different concentrations. A model for evaluating the distribution of the droplet size with respect to time and they found that the droplet size distribution is independent of the surfactant mixing time and the temperature that controlling the droplet inner surfaces. They also found that the critical radius RP^* will be in microns so that the optical microscopy will not be valid for measurements and substitute it by more experimental. They found that the model size distribution n(R) in equation (3) of their paper gives a good results and is similar to that when using optical measurements [15].

The concentration of the emulsifier affects the monomers emulsions in the stability and the size of the droplets. The emulsion droplet size was studied using the ultraviolet-visible transmission spectrum to give the concentration of the monomer emulsion. Also they used the technique of separated phases to measure the stability of the emulsion too.

The given results were used to build correlations that related the stability of the emulsion and also the droplet size measurements. These obtained correlations showed that the optimum emulsifier concentration that gives the highest stability was 4 wt% of monomer, lower clear volume with time and closer distribution of drop size [16].

The distribution inside and outside an emulsion droplet of a phospholipids was held to obtain the relation to the stability of the emulsion. The emulsion was prepared by many mixtures of Iysophosphatidylcholine (LPC), n-decane and water containing HCI, NaCI or NaOH and phosphatidylcholine (PC). Lanthanide ion Pr3+ was used to show quantitative the phospholipids measurements in external and internal aqueous phases. By the treatment of PC in the aqueous phase by using phospholipase, the phospholipids were suggested to be coherent of PC. As a result, the PC-LPC emulsion and its phospholipid distribution changed the interfacial absorption force and the balance of their hydrophile-lipophile. The majority of the phospholipids located inside and outside the interface will stabilize the emulsion. By increasing the lamellar PC, the aqueous layer separation increased and the PC ratio inside decreased.[17]

The possibility of using walnut oil as a fat base of emulsion to create a stable emulsion system was studied. They found that an emulsion with 6 pH will show a smallest average droplet size and the emulsion was about 1-10 ml for 4 weeks as storage test. A formula was determined to give the dispersion coefficient: $k = \frac{(a-b)}{c}$ Where:

a: the largest fat droplet size for 90% of all particles

b: the largest fat droplet size for 10% of all particles

c: the largest fat droplet size for 50% of all particles.[18]

The effect of rice oil on the long-term stability was detected and investigated by using six different emulsions and its stability was detected empirically and by using computer simulation. It was found that 50g of oil and 1.2 g of thickener in an emulsion will give the highest stability. The empirical relations was held by using computer software and it showed that for getting a stable emulsion it should contain from 0.94 to 1.19 g of thickener and 35.93 to 50 g oil. All these results were obtained based on Kleeman's method which gives flexibility on computing and processing the data. The physical change on the system can be neglected and the droplet size was constant for all the storage period [19].

Because of the advantages of the diesel engines in the industry and transportation, many studies were dedicated to increase its efficiency, but in the same time, many of these studies focused on decreasing the pollutions that get out of it. Adding water to the diesel (W/D) shows a significant reduction of harmful pollutions. Two researchers found that the optimum ratio between water and diesel emulsion should be 10-20% for two minutes of mixing time and 15000 revolutions. Also they found that a surfactant should be used for a percentage of 0.2% and the resulting emulsion stayed stable for one month and ten days. They infer that if the concentration of the water increase then the instability of the emulsion will increase and then the concentration of the surfactant is 2% for 40% W/D emulsion and the number of mixing revolution. They found that there is a relation between the distribution of the water droplet and the number of mixing revolution, which the water distribution will decrease with the increase of the number of the mixing revolution [20].

Table 2-1: Summarization the change on the droplet size

Author	Investigation	Results	Effective material used	Working Fluid
Hofman et al. (1991)	• Emulsion changes between diluted decane +CClR4R using Na Aerosol OT and Na oleate as stabilizers. • electrostatic repulsion difference between them	• The electrostatic repulsion was feasible when the interfacial tension is lower than 0.1 mN/m. • They found that Na oleate gives more stability than AOT emulsions for low coagulation	• Na Aerosol OT and Na oleate as stabilizers	Decane +$CClR_4R$ and water
Lee et al. (2002)	• The formation of (S/F/W) double emulsion using (PFPE–OH) and a fluorosurfactant.	• For stability, they make the silicon in the inner part and the fluorocarbon as a shell part. • Fluorosurfactant should be used for more stability.	• silicone,perfluoropolyethoxy methoxy difluorohydroxy ethyl ether (PFPE–OH). • Fluorosurfacta-nt.	• silicon-in fluorocarbon-in-water(S/F/W) double emulsion
BUTLER et al.(2004)	• The stability of nematic emulsions. • Evaluate the distribution of the droplet size with respect to time.	• The droplet size distribution is independence of the surfactant time and the temperature. • Model size distribution n(R) in equation (3) gives a great results.	• A nematic thermotropic emulsion	• crystal liquid in water
Celis et al. (2009)	• The effect of the emulsifier concentration on the monomer emulsion droplet size and stability	• Emulsifier concentration that gives the highest stability was 4 wt%, thus lower cleared volume with time.	N/A	N/A

CHIBA et al. (1990)	• Relationship between the Emulsion Stability and • Phospholipid Distribution in the Aqueous Phases • Inside and Outside of an Emulsion Droplet	• The PC and LPC emulsion and its phospholipid distribution will obtain a change in the interfacial absorption force. • Increasing the lamellar PC, the layer separation will be motivated.	• Iysophosphatidylcholine (LPC) • n-decane and water containing HCI, NaCI or NaOH • phosphatidylcholine (PC).	N/A
Kowalska et al. (2015)	• Walnut oil Water-Based Emulsions Formed at Different pH and its effective of droplet size.	• Emulsion with 6 pH will last for 4 weeks for a sample of 1-10 ml. • They determined a formula to give the dispersion coefficient.	walnut oil	Walnut oil Water emulsion
Kowalska et al. (2016)	• Physical Stability and the Droplet Distribution of rice Oil – in - Water Emulsion.	• 50 g of oil and 1.2 g of thickener will give the highest stability. • They get empirical correlations to detect stability.	Rice oil	N/A
M. T. Ghannam et al(2009)	• The effect of adding water to diesel.	• Reduction of harmful pollutions. • 10-20% as ratio, 2 minutes and 15 rev will give the optimum solution. • 0.2%of surfactant will result in 1 month stability. • They found a relation between the water droplets and the number of mixing revolutions.	water	water to the diesel

2.5 The Drag Reducing Polymer effect

The drag reduction of oil-water in 0.0254 m pipe was tested by using two different polymers: polyethylene oxide and Magnafloc 1011. Adding a concentration of 10-15 ppm of PDRA in the water-oil will reduce pressure by 65% especially with high mixture velocities, which will tend to a change in the flow pattern. Generally, they found that the pressure reduction depends on mixture velocity, water fraction, concentration and the molecular weight of the PDRA. Also, they found that when injecting 5 ppm wt of PDRA a pressure drop will occur which will lead to a phase inversion to dispersed flow with a water fraction of (0.33-0.35). A change of the flow regime will occur after injecting the PDRA. This will affect the slug versus stratified flow pattern. They also observed that the salt in water has a negative effect on the effectiveness of the PDRA [21].

Studies were extended to study the effect of DRP on the stability of emulsions. An experiment on 1.27 and 2.54 cm horizontal pipes using both the water and oil soluble polymers was conducted in stable and unstable oil/water and water/oil emulsions to investigate the pressure drop. The emulsion stability will be enhanced by increasing the DRP molecular weight. Increasing the temperature inversely affected the stability of the emulsion. Pressure drops on all emulsion types will increased by increasing the concentration of the DRP only if the DRP used can soluble in the external phase of the emulsion. At the same turbulence intensity, adding all different DRP types will not be affected by the diameter of the pipe [22].

Studying the effect of the pipe diameter on the effectiveness of the DRP in oil/water horizontal pipes (25.4 and 19 mm) showed that drag reduction can reach its maximum by only injecting 10 ppm of DRP (60% for 25.4 mm and 45% for 19 mm pipe). The

experiments also showed that dual and stratified flow were extended only when the presence of DRP. The dual continuous flow in 19 mm pipe is larger than the other pipe diameter (25.4 mm), while the increase on the stratified flow in the 25.4 mm pipe is more. The decrease of the dispersed region of 19 mm pipe is larger after adding DRP especially for dispersion of oil in water .The drag will be at minimum value on the larger pipe diameter and the maximum drag reduction will occur when oil is dispersed on water [23].

The organoclays (OC) were tested on two different diameters (0.0254 and0.0127 m in horizontal) to study the effect of the pressure drop on water /oil emulsion. The OC added to the stable emulsion was 0.3 water volume fraction and 0.7 (concentrated). As the concentration of the OC increased, the viscosity of the emulsion will decrease. A reduction of 25% in the pressure drop will appear when using the concentrated emulsion for the both diameters, whereas for the diluted in laminar flow, the pressure drop will not be significant. In turbulent flow, increasing the OC concentration will lead to a drop in the pressure. When the friction factor was studied it showed an acceptable value in laminar flow (for single phase) but a reduction in the turbulence flow (for multiphase) [3].

The reduction of drag in oil-water multiphase flow was investigated using ultra high molecular weight sulfonate polyacrylamides in 30.6 mm pipe (horizontal). Because of the acrylamide tert-butyl sulfonic acid (ATBS), the polymer will be negatively charged. The study held at oil with 30P°PC, viscosity of 18.6 cP and a density of 0.886 g/cmP^3P as the oil phase. With a concentration of the polymer more than 20 ppm, the drag reduction will be the minimum. When using the oil as the continuous phase, the oil fraction will

inversely proportional to the drag reduction. While, the increase in the mixture velocity will lead to an increase in the drag reduction especially higher than 10 ppm for polymer concentration and 1 m/s for mixture velocity [24].

Using the surfactants and the nanoparticles (cosurfactants) in oil/water emulsion will enhance the recovery of the heavy oil. Studies showed that the injecting of nanoparticles will not increase only the emulsion viscosity but also the stability of the emulsion, too. The recovery can reaches 40% IOIP (initial oil in place) for crude oil with 50°C and 350 mPa as viscosity. The study also showed that we can control the thicken of an emulsion by using nanoparticles to reach the desired mobility needed [25].

From the thermodynamically viewpoint the emulsion systems tends to separate into two original phases after a period of time. Researches have been held to know the effecting surfactants or techniques that affect the two phase separation. They believed that the thin film between two collided droplet is the key factor to the stability in the entire emulsion [26].

Using of nanoparticles in dilute emulsion to get a stable mixture has large applications. The major common use of these nanoparticles is in highly concentrated emulsions. Hydrophilic and hydrophobic particles are kinds of that nanoparticles used for high concentrated emulsions. The studies showed that high hydrophobicity and hydrophilicity will tend the aqueous phase or oil phase separated and the tendency of forming an emulsion will minimize. Using an emulsifier such as SMO can tend to create a stable emulsion under shear but not long term stability in highly concentrated or overcooled emulsions. Using SMO with the optimum silica with a good degree of hydrophobicity in an emulsion will give a good result of stability [10].

Table 2-2: Summarization the effect of DRP

Author	Investigation	Results	Effective material used	Working Fluid
Al-Yaari et al(2009)	The drag reduction of oil-water in 0.0254 m pipe was tested by using two different polymers.	• Adding 10-15 ppm of PDRA to the emulsion will decrease the pressure 65%. • Adding PDRA will change the flow regime. • Salt in water gives negative effect to the PDRA.	• Polye thylene oxide. • Magn afloc 1011.	water-oil
Al-Yaari et al(2013)	Stability of emulsions on 1.27 and 2.52 cm, horizontal pipe using both water and oil soluble.	Increasing the DRP molecular weight will enhance the stability • Increasing the DRP concentration will decrease the pressure only if the DRP can soluble in the external phase.	N/A	water-oil
Al-Wahaibi et al (2012)	The effect of the pipe diameter on the effectiveness of the DRP in oil/water horizontal pipes (25.4 and 19 mm).	Drag reduction can reach its maximum by only injecting 10 ppm of DRP. Dual and stratified flow extended with the presence of DRP. Drag will be minimum on larger diameter. Drag reduction will be maximum	N/A	Oil/water emulsion

		when oil is dispersed on water.		
Al-Yaari et al(2014)	Study the effect of the pressure drop on water /oil emulsion using organoclays on two different diameters (0.0254 and0.0127 m in horizontal).	25% reduction in the pressure will appear when using the concentrated emulsion foe both diameters. In turbulent flow, increasing the OC concentration will reduce the pressure and also the friction factor only for two phase flow.	Organoclays(cloisite 15A)	water/oil emulsion
Eshrat et al(2015)	The reduction of drag in oil-water multiphase flow was investigated by using a high molecular weight sulfonate polyacrylamides in 30.6 mm pipe	For more than 20 ppm of the concentrated polymer, the drag reduction will be minimum. For higher than 10 ppm for polymer concentration and 1 m/s for mixture velocity, the drag will increase.	Sulfonate polyacrylamides	water/oil emulsion
Pei et al(2015)	Using the surfactants and the nanoparticles in oil/water emulsion to study the recovery of the heavy oil.	The stability and the viscosity of the emulsion will increase by injecting the nanoparticles. Using nanoparticles can control the thickening of an emulsion	N/A	oil/water emulsion

		for transportation processes.		
O. D. Velev et al (1997)	Study the separation of the emulsion on a thermodynamically viewpoint.	The thin film between two collided droplets is the key factor to the stability in the entire emulsion.	N/A	N/A
N.N. Tshilumbu et al (2014)	Effect of Nanoparticle Hydrophobicity on Stability of Highly Concentrated Emulsions.	High hydrophobicity and hydrophilicity will tend the tendency of forming an emulsion will minimize Using SMO with the optimum silica with a good degree of hydrophobicity in an emulsion will give a good result of stability	N/A	N/A

2.6 The effect of salt and surfactants

Oliver [27] used water and methyl myristate (1:1 by volume) At 20°C and, with poly(4-vinylpyridine)/silica nanocomposites micro gel particles as a sole emulsifier to investigate two-phase non-Newtonian flow in pipes. As the pH value decrease, the hydraulic diameter of these particles will get larger. The oil/water emulsions prepared at 3.4pH will exhibit creaming but will be stable to coalescence. The coalescence of the emulsion will be very unstable at a value below 3.3 ph. The demulsification of the

continuous emulsion will take place rapidly below 3.3pH and will become charged and thus will detach from the interface. When the salt concentration is 0.24 mole/kg , the pH was fixed at 4 and adding the sodium chloride to the emulsion then the dispersion will increase and the emulsion will exhibit an stability [27].

Injecting salt into liquid paraffin-in-water emulsion was studied by charging a plate such as layered double hydroxides (LDHs). The stability and the formation of the emulsion will be affected by zeta potential particles. It was found that if the salt concentration increased then the zeta particles will decrease. The main cause of the emulsion stability is the structural build up in the LDHs dispersion and that will happened only if the particle zeta potential will decrease leading to an adsorption of these particles in the oil-water interface but important for emulsion formation [28].

The effect of the salt on the emulsion microwave demulsification process was studied. The heating will increase by increasing the ionic species in the emulsion. The experiment was held by using 15000 and 30000 ppm of NaCl. The increase the salt content will decrease the separation efficiency and playing with the ratio of the salt may form new phases and can enhance the partitioning of the surfactants. On the other hand increasing the hydrophilicity by increasing the salt content will also enhance the stability[29]. To know the stability of any emulsion it was important to give the degradation of the emulsion a sufficient amount of studying. Firstly it was important to know the mechanism the emulsion happened and the changes in its microscopic structure. Three microscopic mechanisms happened in the emulsion: coalescence, diffusion and dewetting .Some structures are very complicated, double emulsion is one of them which eventually will isolate from the continuous phase because of catching some additives. The magnetic

emulsion also another example of the complicated emulsion. It is made from magnetic fluids that are immersed in oil emulsion to result in a double colloidal structure. After this critical researches the scientists can be able to predict the life time of any emulsion once they study the microscopic structure of that emulsion [30]. Because of the advantages of the diesel engines in the industry and transportation many studies have been held to increase its efficiency, but in the same time many of these studies have been held to decrease the pollutions that get out from it. Adding water to the diesel (W/D) shows a significant reduction of harmful pollutions. Two researchers found that the optimum ratio between water and diesel emulsion should be 10-20% for two minutes of mixing time and 15000 revolutions. Also they found that a surfactant should be used for a percentage of 0.2% and the resulting emulsion stayed stable for one month and ten days. They infer that if the concentration of the water increase then the instability of the emulsion will increase and then the concentration of the surfactant is 2% for 40% W/D emulsion and the number of mixing revolution. They found that there is a relation between the distribution of the water droplet and the number of mixing revolution, which the water distribution will decrease with the increase of the number of the mixing revolution [20].

Table 2-3: Summarization the effect of salt and surfactants

Author	Investigation	Results	Effective material used	Working Fluid
Binks et al (2006)	Effects of pH and salt concentration on oil-in-water emulsions stabilized solely by nanocomposite microgel particles.	Coalescence of the emulsion was unstable at a value below 3.3 ph. The demulsification of the continuous emulsion will take place rapidly below 3.3pH. When the salt concentration is 0.24 mole/kg, the pH was fixed at 4 and adding the sodium chloride to the emulsion then the dispersion will increase.	Poly (4vinylpyridine)/silica Nano composites micro gel particles as a sole emulsifier.	Oil/water emulsion
Yanget al (2006)	Pickering emulsions stabilized solely by layered double hydroxides particles	Increasing the salt concentration then the zeta particles will decrease The main cause of the emulsion stability is the structural build up in the LDHs dispersion	Layered double hydroxides (LDHs).	Liquid paraffin-in-water emulsion.
Fortuny et al (2006)	Effect of Salinity, Temperature, Water Content, and pH on	The increase in the salt content will decrease the separation efficiency.	N/A	N/A

	the Microwave Demulsification of Crude Oil Emulsions.	Playing with the ratio of the salt may form new phases and can enhance the partitioning of the surfactants.		
K. Pays(2009)	Understanding the Stability and Lifetime of Emulsions.	Predict the life time of any emulsion once they study the microscopic structure of that emulsion.	N/A	N/A
M. T. Ghannam et al(2009)	Stability Behavior of Water-in-Diesel Fuel Emulsion.	• Reduction of harmful pollutions. • 10-20% as ratio, 2 minutes and 15 rev will give the optimum solution. • 0.2%of surfactant will result in 1 month stability. They found a relation between the water droplets and the number of mixing revolutions.	water	water to the diesel

2.7 Effect of temperature

PIT (Phase Inversion Temperature) method for emulsifying oil in water (O/W) was studied by [31] using 3 wt% of polyoxyethylene nonylphenylether as a function of change in temperature and they found the following:

- The emulsion temperature affects strongly the droplet size of the emulsion.

- By using the phase inversion temperature the droplet diameter will appear very small but stable.
- Stability can be obtained for oil-water emulsion the storage temperature is higher by 20-65 °C.
- Rapid cooling for emulsion which emulsified using PIT, will lead to stable emulsion [31].

The temperature effectiveness to the stability and the interfacial tension of water-oil emulsions using polyoxyethylene nonylphenylether as a stabilizer was studied. Being close to PIT will lead to tiny value of the interfacial tension. By increasing the temperature the diameter of the droplets will increase. When the PIT of the emulsion is lower by 10-40°C, then the water in oil emulsion will show stability [32].

The demulsification performance was studied when using a microwave irradiation for 15 minutes as a temperature source. Increasing the radiation will increase the demulsification degree. Viscosity will decrease when increasing the radiation (temperature) which will also improve the demulsification [29].

Using the critical electrical field techniques to measure the effect of temperature on the stability (of 27-crude oil) showed that the molecular forces between molecules will break down when increasing the temperature and then the viscosity will decrease. Some of the crude oil types can be treated as a Bingham plastic type (waxy crude) [33].

Table 2-4: Summarizing the effect of temperature

Author	Investigation	Results	Effective material used (Polymer)	Working Fluid
SHINODA et al(1969)	The Stability of O/W type emulsions as functions of temperature and the HLB of emulsifiers: The emulsification by PIT-method.	Stability can be obtained for oil-water emulsion the storage temperature is higher by 20-65 °C. Rapid cooling for emulsion which emulsified using PIT, will lead to stable emulsion.	Polyoxyethylene nonylphenylether.	Oil-water emulsion
SAITO et al(1970)	The stability of W/O type emulsions as a function of temperature and of the hydrophilic chain length of the emulsifier.	By increasing the temperature the diameter of the droplets will increase When the PIT of the emulsion is lower by 10-40°C, then the water in oil emulsion will show stability	Polyoxyethylene nonylphenylether	Oil-water emulsion
Fortuny et al(2006)	Effect of Salinity, Temperature, Water Content, and pH on the Microwave: Demulsification of Crude Oil Emulsions.	Increasing the radiation will increase the demulsification degree Viscosity will decrease when increasing the radiation (temprature) which	N/A	N/A

		will also improve the demulsification.		
Hemmingsen et al (2007)	Emulsions of Heavy Crude Oils: Influence of Viscosity, Temperature, and Dilution.	That the molecular forces between molecules will break down when increasing the temperature and then the viscosity will decrease.	N/A	27-crude oil

CHAPTER 3

EXPERIMENTAL SETUP AND PROCEDURE

The DRA test loop available at the Center for Refining & Petrochemicals (CRP) at the Research Institute was used for the proposed study to study the effect of the temperature on the pressure drop of the w/o emulsion at different emulsion flow rates.

The flow loop contains two barrels, one for the water and the other for the oil (200-liters for each) and a connection for the air supply. Also, a reciprocating pump is located for adding additives if needed. Two flow rate measurement devices are connected in the oil and water stream lines and can be adjusted using needle valves on each line. The two pumps of the oil and water are rotary pumps with axial face sealing. Water, air and oil can be separated in the separator or using cyclone and separator which are connected to the outlet of the test section. The total length of the stainless pipes is approximately 5 m with an outer diameter of 0.5 inches and an inner diameter of 0.4 inches. This 5 m pipe divided into a horizontal and a vertical section. The horizontal section contains two pressure transducers to measure the pressure difference, one across 1 m length and the other along 1.5 m to detect the small pressure difference. There is also an acrylic section (20 cm) at the end of the horizontal section to inspect the flow behavior. The fluid can be directed to the phase separator where water and oil can be separated by gravity or alternatively to the cyclone whose outlet is connected to the phase separator. All this parts showed in the **figure 3-1**:

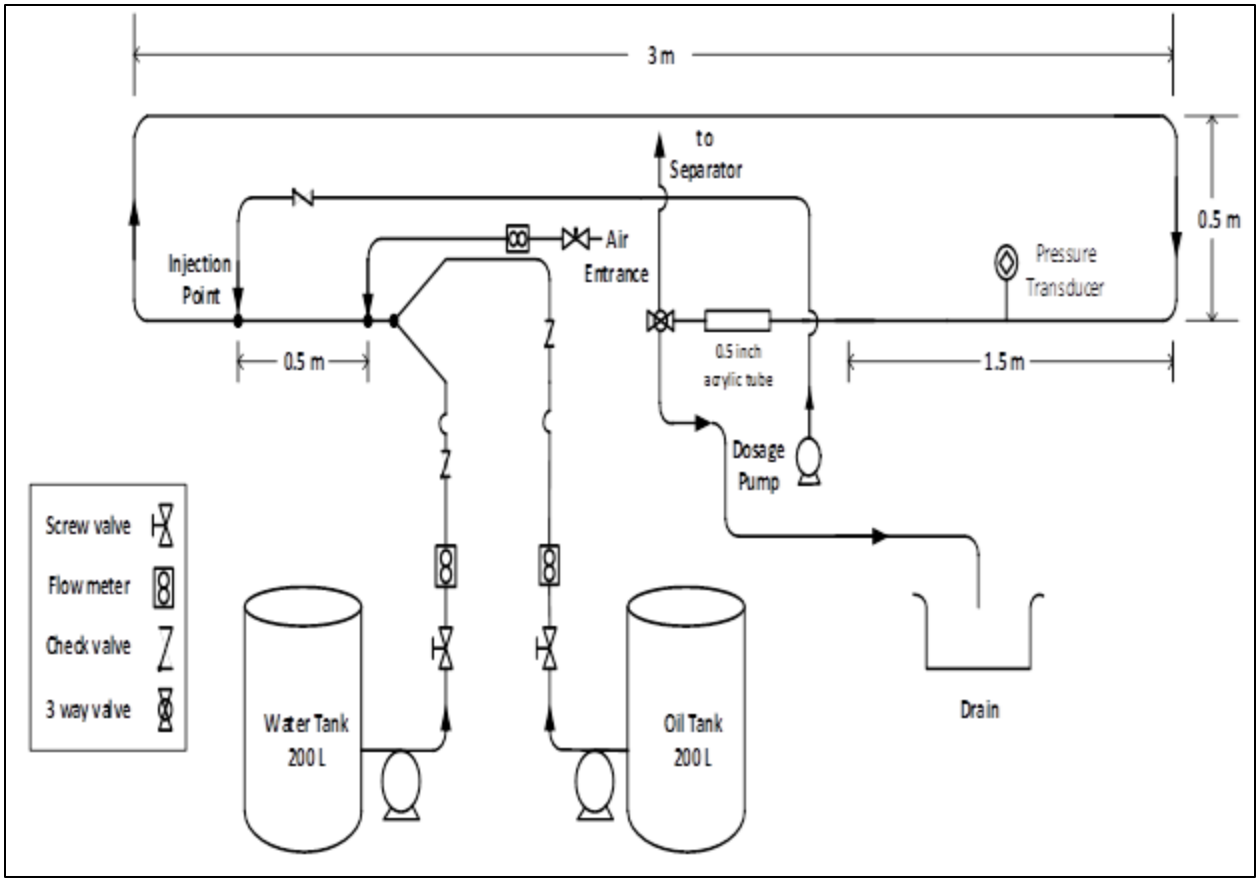


Figure 3-1: Sketch of the system Layout

Figure 3-2: 3-D image for the system.

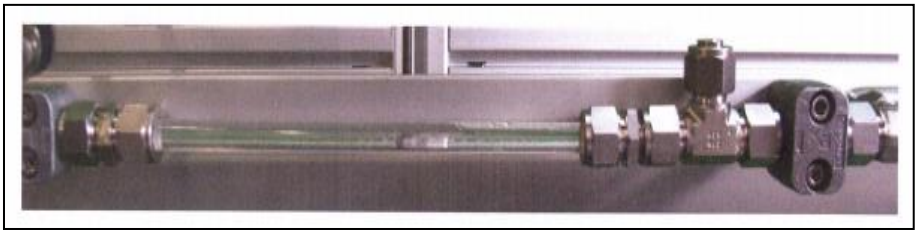


Figure 3-3: Acrylic section for flow investigation

Figure 3-4 shows the dosage reciprocating pump that uses to inject additives inside the loop. It is manually adjusted and has different flow speeds up to 1380 rpm and hence, different concentrations of the additives inside the system can be made.

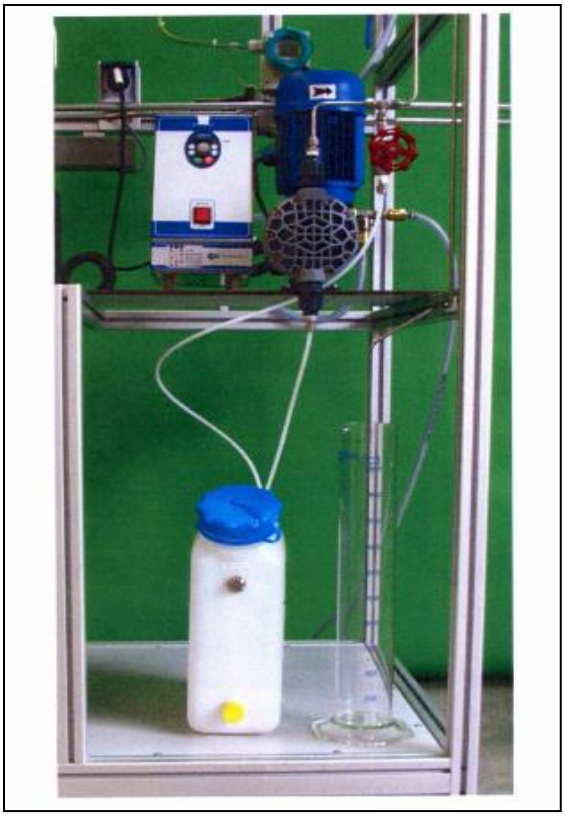


Figure 3-4: Additives injection system

The electromagnetic flow meter is used to measure the volume flow rate of water up to 40L/min.; a check valve is connected after the flow meter to prevent back flow of water.

Figure 3-5: Water flow rate measuring device

The instrument that used for measuring the pressure difference is the SITRANS P DSIII HART series pressure transmitter. It is mounted about 3.5 m downstream the mixing section but also connected 1.5 m apart. This 3.5 m was selected after calculations to insure the fully developed region as shown in the figure below.

Figure 3-6: Pressure Transmitter

A data acquisition system is used to show recorded and illustrate figures for the utilization of the data collected from the experiments. The figure below shows the display screen for the data acquisition system that have a port to connect with the computer with a specific software that give the data collected for the temperature, pressure difference and the volume flow rate.

Figure 3-7: Data acquisition system screen

The properties of water (the water contains 2%mass of NaCl), diesel, organoclay (closite 20A) and the emulsifying agent are explained in **Table 3-1**, and **3-2**:

Table 3-1: The density and dynamic viscosity of the water solution and diesel

T (°C)	ρ_w (Kg/m3)	μ_w (Pa.s)	ρ, oil(Kg/m3)	μ, oil(Pa.s)
25	997.3	0.000912489	818.7833	0.003510943
30	995.65	0.000800117	814.4417	0.003026465
35	994	0.000722202	811.104	0.002631221
40	992.2	0.000655688	807.6508	0.002416491
45	990.22	0.000598494	803.06842	0.002184346

Table 3-2: Properties of the emulsifying agent

Product name	ARMAC-T
Form	liquid
Flash point	64°C
pH	5.5-6.5
Density	950 kg/m^3@16°C
Viscosity	<1000 cp@20°C
Hydropile-lipophile balance (HLB)	6.8

3.1 Preparation of the emulsion

Two types of emulsions have been prepared; the first was the 70% water in 30% oil, w/o emulsion and the second was the 50/50, w/o emulsion and for the both emulsions the oil must be the outer phase (continuous phase). The details are given below:

3.2 Preparation of the 70/30, w/o emulsion:

The 70/30, w/o emulsion has been prepared as follows:

1. Salt was added to the distilled water with 2% mass of the water weight to make the water more ionic to get closer to the sea water. Then, it was mixed until the solution become homogenous.

2. The emulsifier was added to the oil at 0.6% of the oil volume while the oil has been mixed with 8000 rpm for 5 minutes.

3. After the 5 min, the water was added in a rate of 1 L/min.

4. The voltmeter was used every 2 min to check the outer phase of the emulsion and it takes about 15 to 20 min to form a stable, oily outer phase emulsion. In case if these steps was not followed exactly, the resulted emulsion will have the water to be the continuous phase (external phase).

3.3 Preparation of the 50/50, w/o emulsion:

The same as the 70/30, w/o emulsion except that the emulsifier percentage is 0.6% of the total emulsion volume.

For the two types of the emulsions, it was found that the HLB (Hydrophile-Lipophile Balance) value was below 10 and this supports the fact that the prepared emulsion is water in oil.

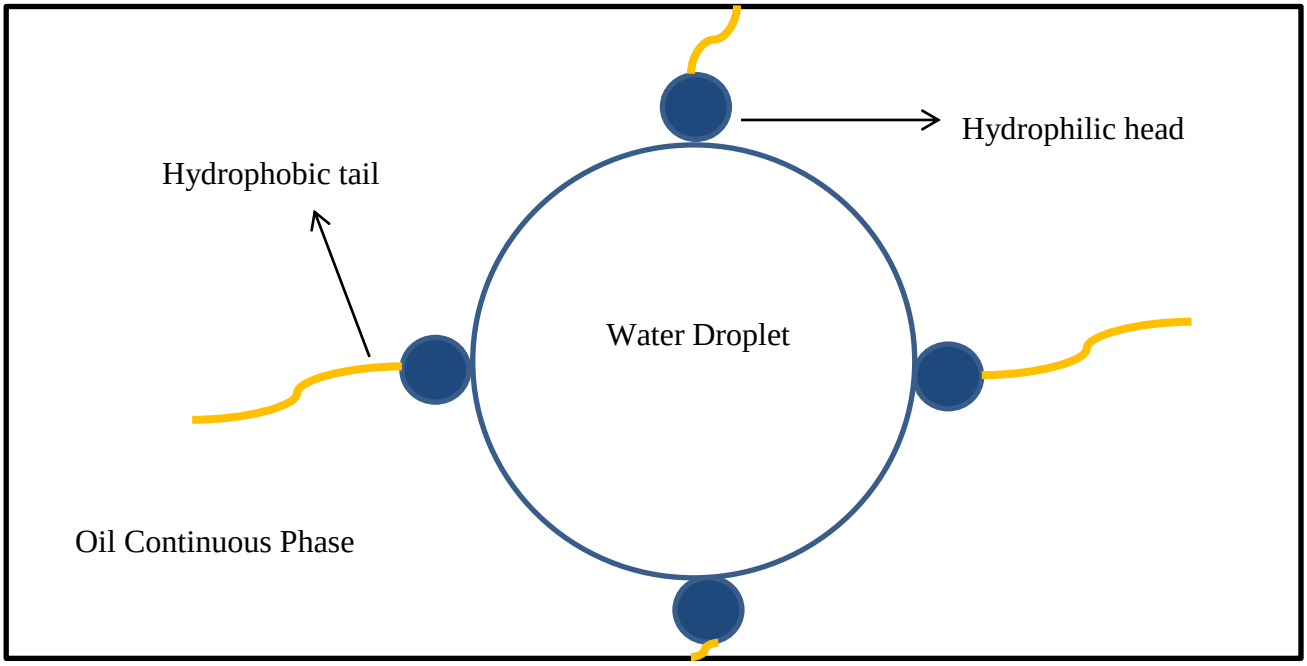


Figure 3-8: Structure of the water droplet inside the oil.

Figure 3-8 shows a simple structure of the w/o emulsion with emulsifier. after adding these components together, the following interaction will happen:

- Diesel.
- Clay (cloisite 20A): $(CH_3)_2(HT)_2N^+$
- Emulsifier (ARMAC-T)
- Water (H^+-OH^-)
- Salt (Na^+-cl^-)

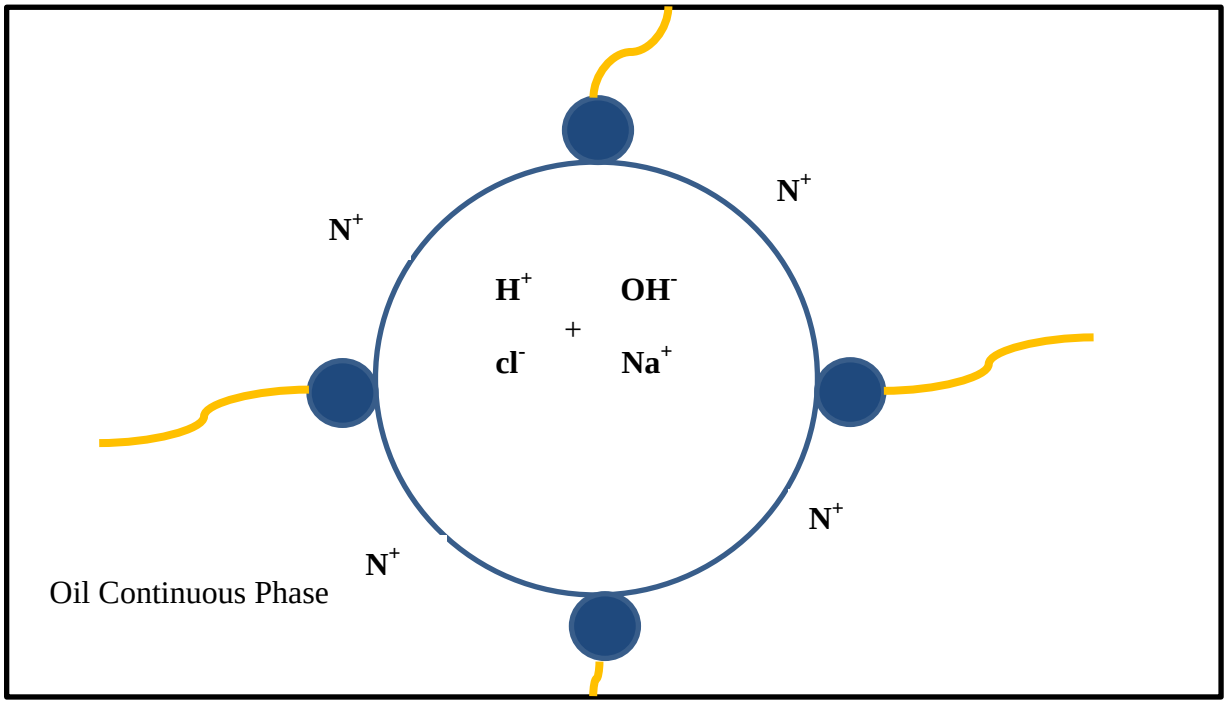


Figure 3-9: The interaction of all components in the prepared emulsion.

3.4 Calibration of the flow loop:

The flow loop was calibrated by calculating the pressure difference using Blasius formula for the fiction factor and the pressure transducer for measuring the pressure difference along 1.5 m. **Figure 3-9** shows a good agreement between the calculated and the measured one.

The Blasius friction factor for turbulent flow calculated by:

$$f = \frac{0.3164}{\mathrm{Re}^{0.25}}$$

$$\mathrm{Re} = \frac{\rho D V}{\mu}$$

And the frictional pressure drop calculated using:

$$\Delta P = \frac{f \rho V^2}{2D}$$

Where:

f is friction factor.

Re is Reynolds number.

ρ is liquid density.

V is average liquid velocity.

D is inside diameter of the pipeline.

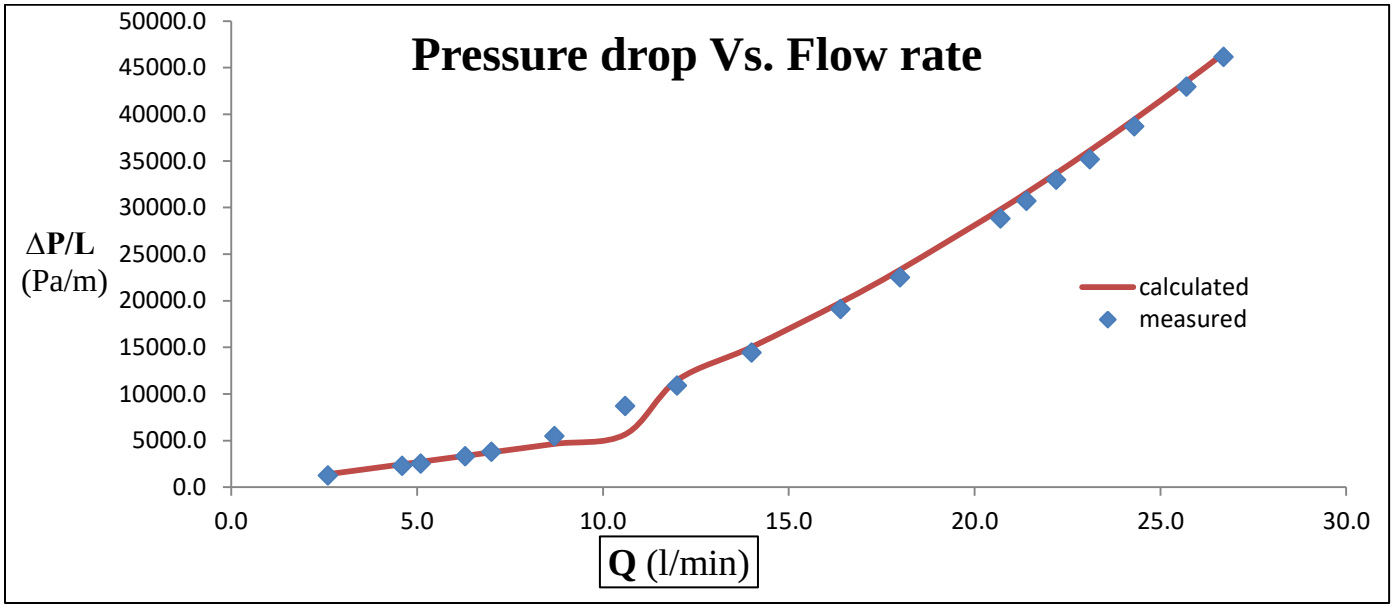


Figure 3-10: Variation of the pressure drop versus flow rate for the single phase water flow.

CHAPTER 4

RESULTS AND DISCUSSION

All experiments were conducted in the DRA test loop available at the Center for Refining & Petrochemicals (CRP) at the Research Institute which was explained in detail in chapter 3. These experiments were performed mainly to investigate the effect of the temperature on the pressure drop of a 70/30, w/o will be explained in section 5.1. In section 5.2 all the 50/50, w/o emulsion experiments will be explained.

The emulsifier (ARMAC-T) was used for both emulsions first and then 100ppm of organoclay (closite 20A) was added to see the effect of the clay on the pressure drop reduction.

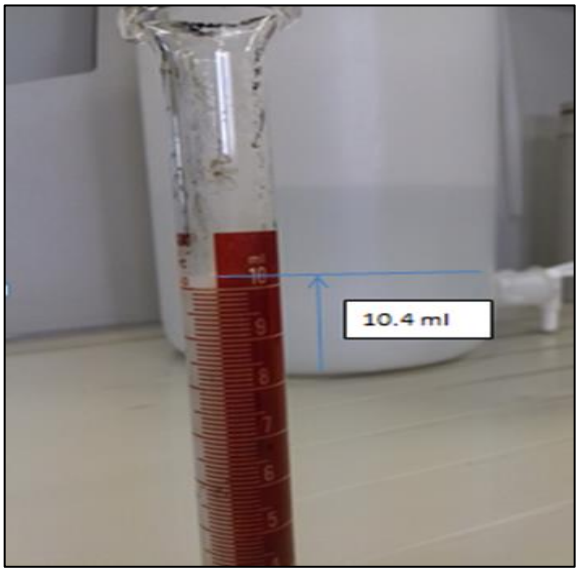
4.1 70/30, w/o emulsion:

4.1.1 Stability

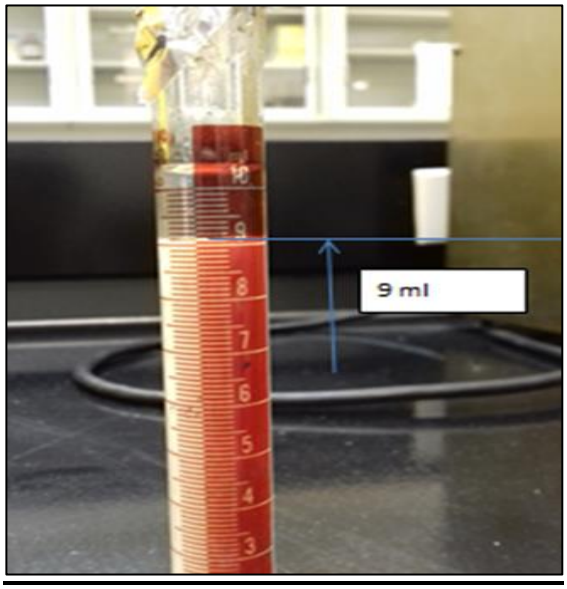
Stability tests have been done for the two types of the emulsions (70/30 and 50/50, w/o emulsions) Samples of the respective emulsion was kept inside an oven at a temperature of 45 °C and monitored with time. The percentage of the separated oil volume fraction was reported. The results of the two emulsions are listed below; one test was for emulsion with only the emulsifier (ARMAC-T) and other with (ARMAC_T + 100ppm closite 20A):

4.1.2 Stability of 70/30 emulsion with only emulsifier (ARMAC-T):

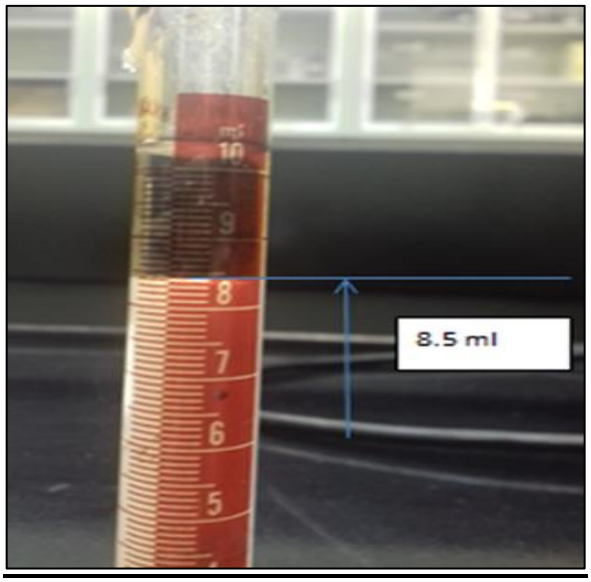
The stability test for this emulsion given in **table 4-1**:



(a)



(b)



(c)

Figure 4-1: The emulsion (with only ARMAC-T) volume:(a) right after mixing, (b) 5 hours later and (c) 26 hours later.

Table 4-2 shows the detailed emulsion volume for 50 hours:

Table 4-1: The emulsified emulsion stability with time:

Time (hours)	Emulsion vol (ml)
0	10.40
5	9.00
22	8.50
26	8.50
50	8.40

This data shows that after 50 hours (two days) at a temperature of 45 °C, the separation was only 2 ml with a separation percentage of 13.4% after 7 hours which is the targeted time.

Figure 4-2 shows the trend that describes the behavior of this emulsion with time:

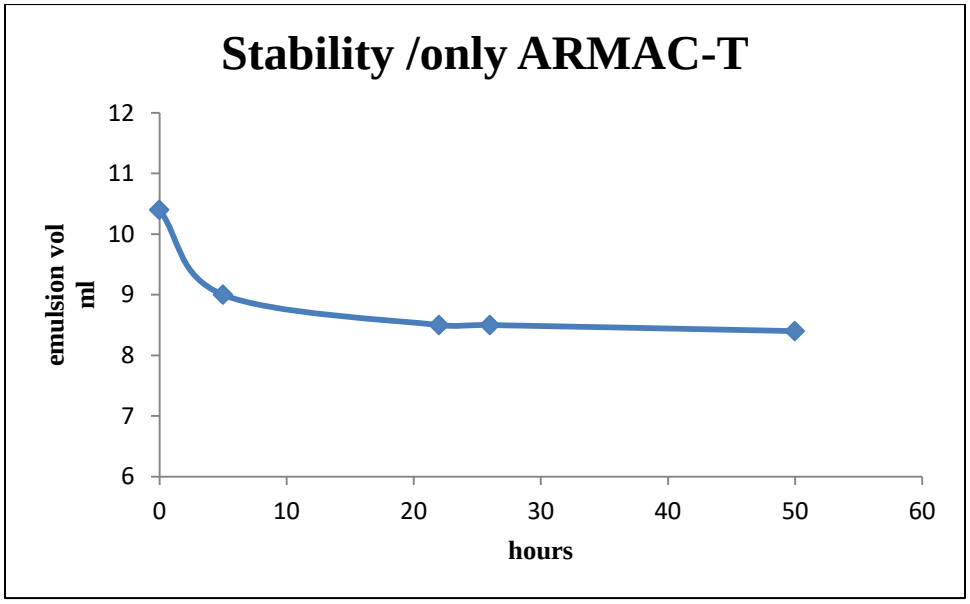


Figure 4-2: The emulsion volume through 50 hours.

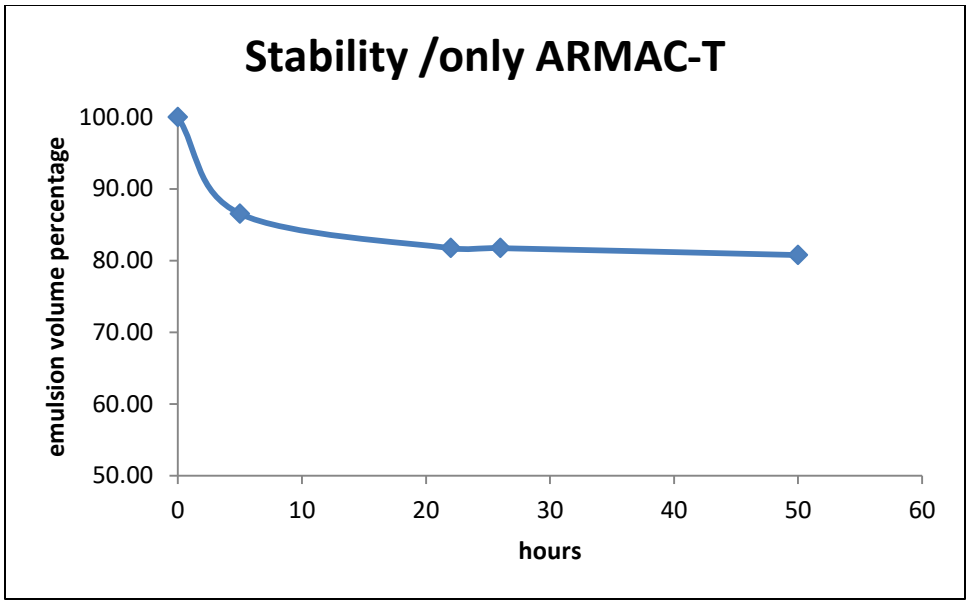


Figure 4-3: Emulsion volume reduction through 50 hours

Moreover, a dilution test was performed to identify the emulsion continuous (external) phase. In this test, one droplet of the formed emulsion is injected in an oil or water pure phase. If droplet disperses, emulsion continuous (external) phase is the same as the used fluid for the test and vice versa.

Figure 4-4: The oily outer phase emulsion floats in water

4.1.3 The emulsion with emulsifier (ARMAC-T) and 100ppm closite 20A:

The emulsion is the same as the previous one (as in part A) but with a 100ppm closite 20A added gradually to the emulsion. In this case also the emulsion was left inside a 45°C oven and then collected the data for the separated oil volume fraction.

The stability test for this emulsion is given below:

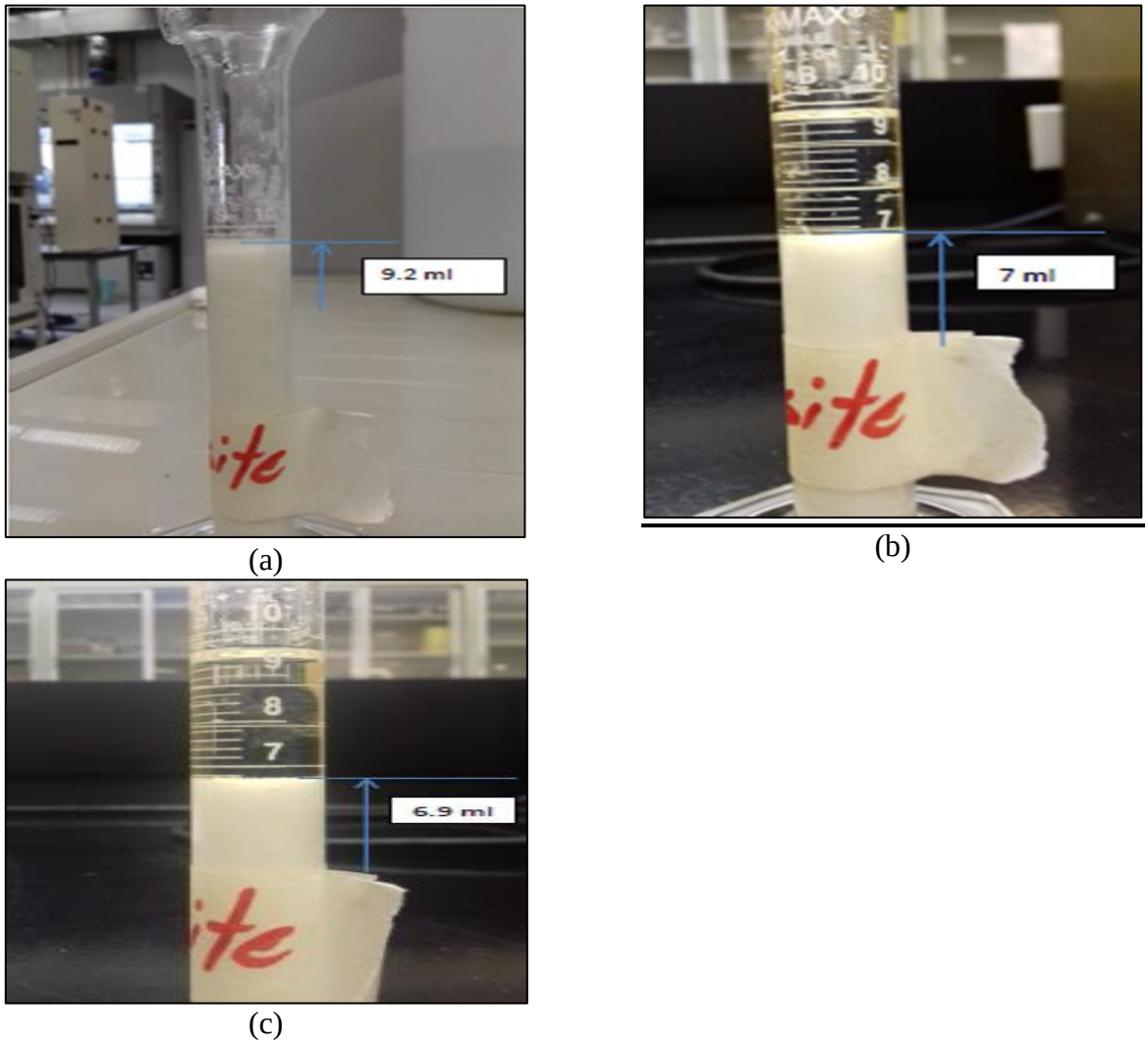


Figure 4-5: The emulsified emulsion +100ppm cloisite 20A volume: (a) right after mixing, (b) 16 hours later and (c) 48 hours later.

This is the detailed emulsion volume for 48 hours:

Table 4-2: The stability of the emulsified emulsion with 100ppm closite 20A:

Time (hours)	Emulsion volume (ml)
0	9.2
16	7.0
20	7.0
44	6.9
48	6.9

The data above shows that after two days (48 hours) the separation of the oil is only 2.3 ml with only a separation percentage of 23.9% after 16 hours although only the targeted time is 6 hours. The figure below describes the behavior of this emulsion during 48 hours:

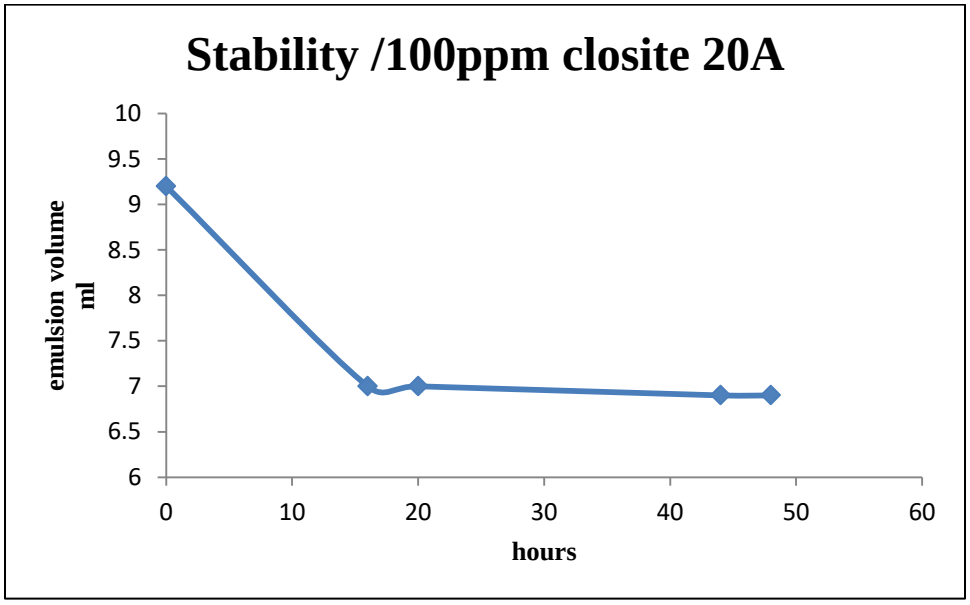


Figure 4-6: Emulsion volume through 48 hours

4.1.4 Rheology

All tests have been done by rheometer device (TA, Discovery HR-3, Hybrid rheometer) for the viscosity estimation while the density was obtained using Anton Paar-DMA 4500M density meter. The tests done for two samples, the first with only emulsifier and the other is with

100ppm organoclay beside the emulsifier. The density and the steady shear are the two emulsion properties of interest in the present application.

4.1.5 The rheology test results for emulsion with only emulsifier agent (ARMAC-T):

All rheological measurements were conducted using the TA, Discovery HR-3, Hybrid rheometer. The results are obtained directly through a computer at different temperatures in **figure 4-7**.

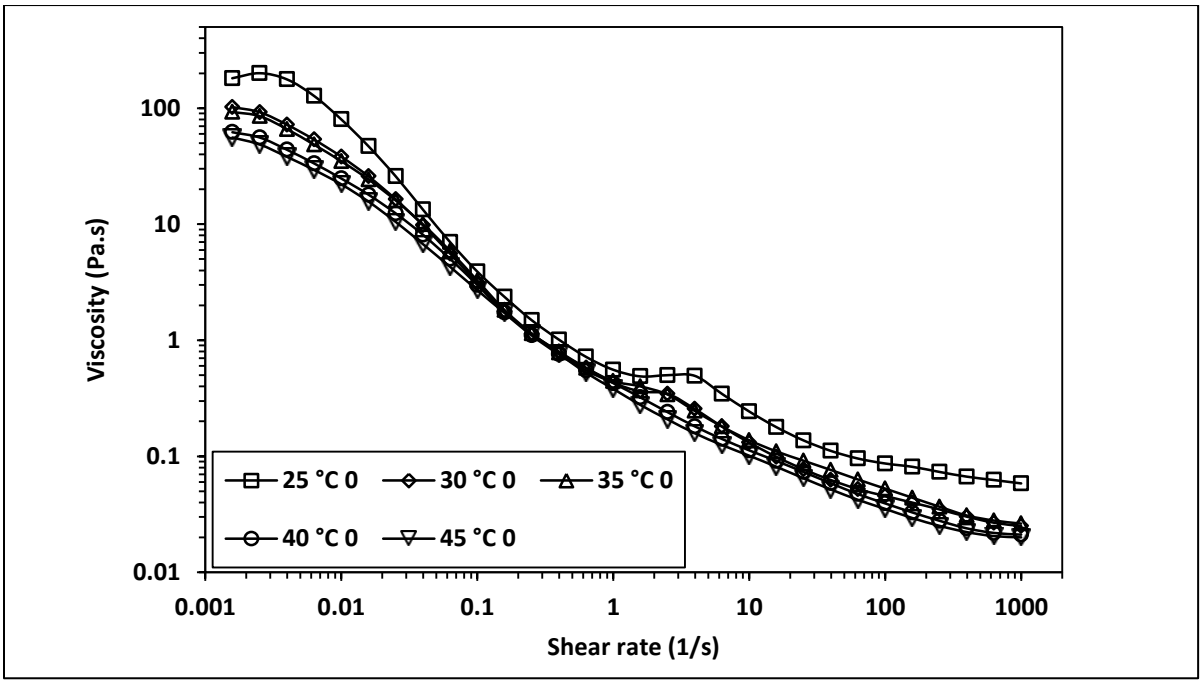


Figure 4-7: Viscosity versus shear rate at different temperatures (only ARMAC-T)

The viscosity at 25, 30, 35, 40 and 45 °C at different shear rate is presented in Figure 4-5. The same temperature range of interest in this study was used also for the pressure drop measurement at these temperatures. The density and dynamic viscosity values at the interested emulsion temperature values are shown in **Table 4-5**.

Table 4-3: Density and the steady viscosity of emulsion at different temperatures:

T (°C)	ρ, emulsion (Kg/m^3)	μ, emulsion (Pa.s)
25	939.74	0.05835
30	937.43	0.025027
35	943.97	0.026278
40	932.24	0.021118
45	929.12	0.02

Increasing temperature from 25 to 45 °C, only decreasing the density by about 1% from the first value. But it is obvious that increasing of temperature affect the dynamic viscosity significantly and that because increasing temperature breaks the bonds between molecules and then the viscosity will decrease.

4.1.6 The rheology test results for emulsion with emulsifier agent (ARMAC-T) and 100ppm organoclay (closite 20A):

The rheological procedure is the same for both cases (with and without closite). After adding 100ppm of the closite 20A the emulsion subjected to the rheological tests and the results is shown in figure 4-6.

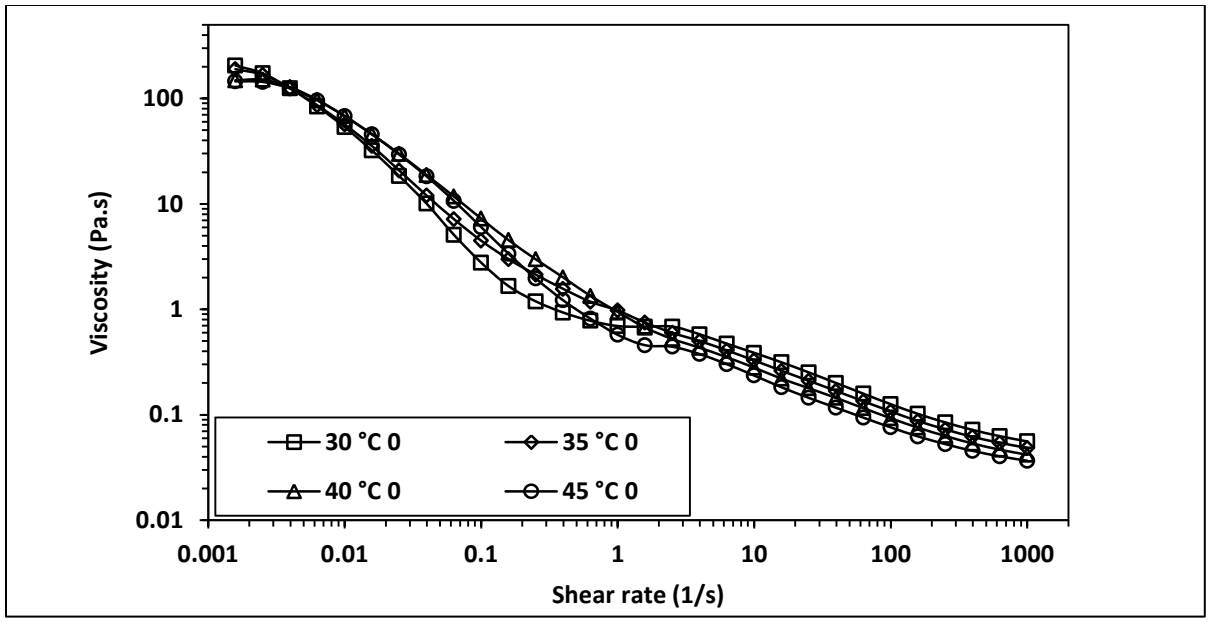


Figure 4-8: Viscosity versus shear rate at different temperatures (ARMAC-T+100ppm closite 20A)

Below is the density and dynamic viscosity values that will be used in experiments.

Table 4-4: The density and the steady viscosity with different temperatures for the emulsion with 100ppm closite 20A:

T (°C)	ρ, emulsion (Kg/m^3)	μ, emulsion (Pa.s)
25	961.67	0.063218
30	959.36	0.055849
35	957.34	0.04848
40	954.56	0.041761
45	951.48	0.0366

It is clear that adding 100ppm of the closite 20A to the emulsion affected firstly the density (the density is higher than the case without closite) and secondly, the closite affects the variation of the density with increasing the temperature.

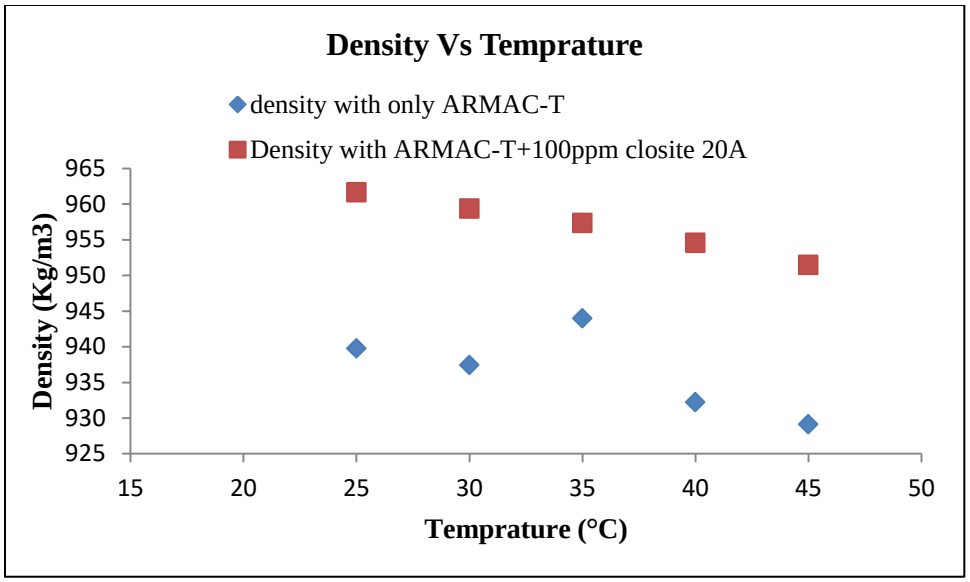


Figure 4-9: The density variation with temperature

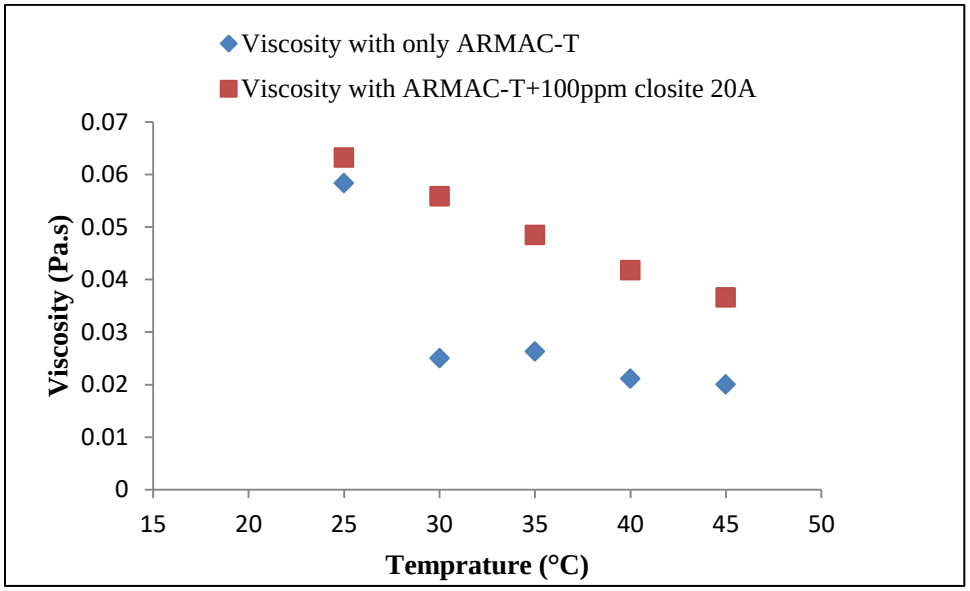


Figure 4-10: The viscosity variation with temperature

4.1.7 Pressure drop variation for the 70/30, w/o emulsion

To investigate the effect of temperature on the pressure drop at various emulsion flow rate using w/o, 70/30 stable emulsion. Brine with 2 wt% NaCl (20 kppm) was used as an aqueous phase. After preparing such emulsions, stability tests were carried out using bottle test, by monitoring phase separation with time. Also, the rheology tests were held at the same time. The same procedure was performed after adding the organoclay to the emulsion as the only emulsifier mentioned earlier. Emulsion type and conductivity tests were conducted by performing dilution tests and conductivity measurement, respectively. The emulsion conductivity test was conducted under static conditions after preparing the emulsion by using a conductivity meter. All of the tested emulsions were W/O with a conductivity of 0 V, which was confirmed by the dilution tests.

The pressure drop of all prepared surfactant-stabilized W/O emulsions were measured at different flow rates taken along 1.5m section of the stainless steel pipeline. All measurements were conducted at steady-state conditions. The emulsion temperature was changed from 25 to 45 °C.

Pressure drop measurement results for emulsion flow in pipe are presented in the figure 4-9 and 4-10:

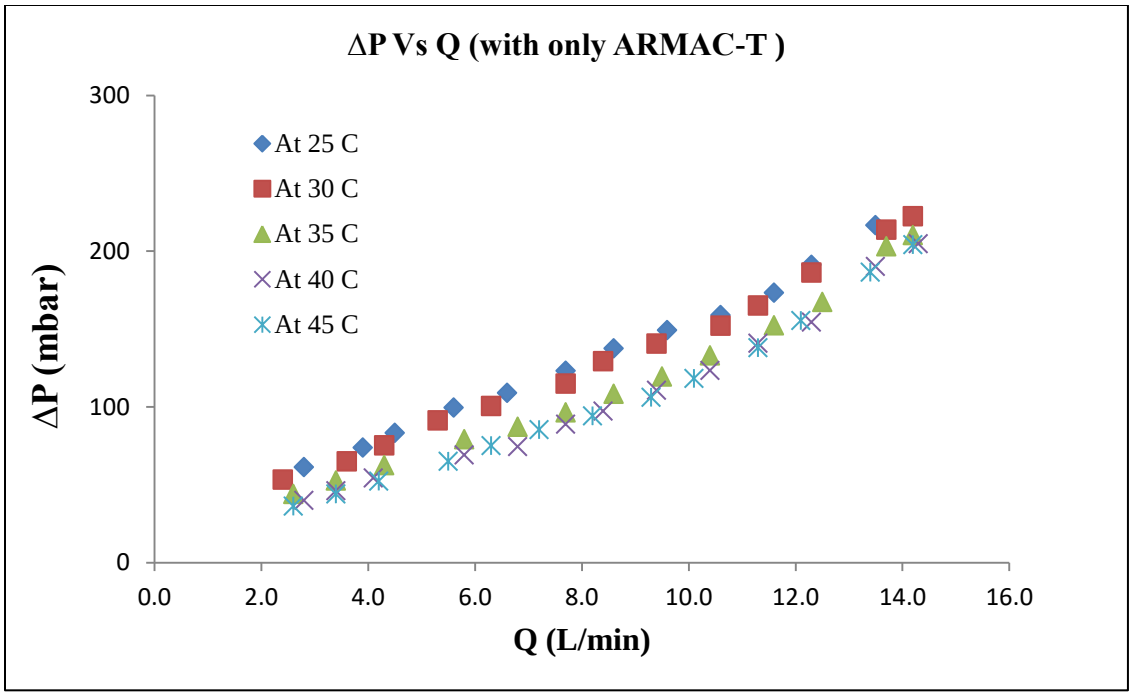


Figure 4-11: Pressure variation with emulsion flow rate at different temperature with the emulsified emulsion (only ARMAC-T)

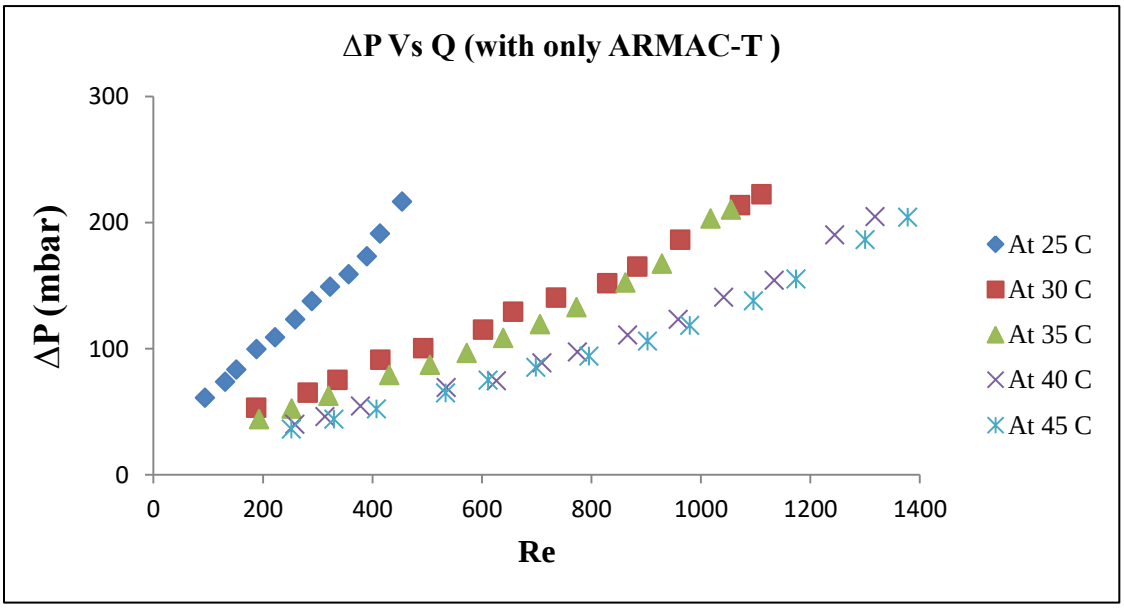


Figure 4-12: Pressure variation with emulsion Reynolds number (Re) at different temperature with the emulsified emulsion (only ARMAC-T)

Figure 4-11 and 4-12 above shows the effect of temperature variation of the pressure drop at different flow rates. Increasing the temperature lead to a decrease in the pressure drop of the

emulsion and this because increasing temperature will lead to break the bonds between molecules and also the shear thinning effect that contribute the decreasing the viscosity and hence the pressure drop. It seems that at high and low flow rates the pressure drop curves get closer values.

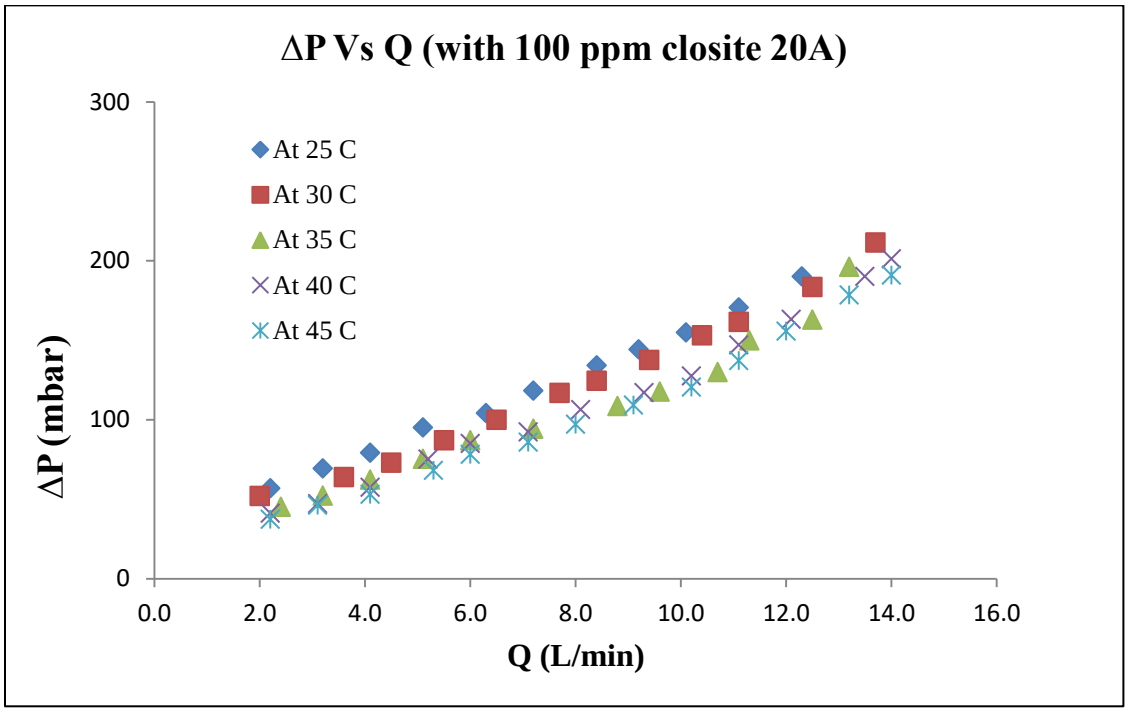


Figure 4-13: The effect of the temperature difference with the emulsified emulsion +100ppm closite 20A

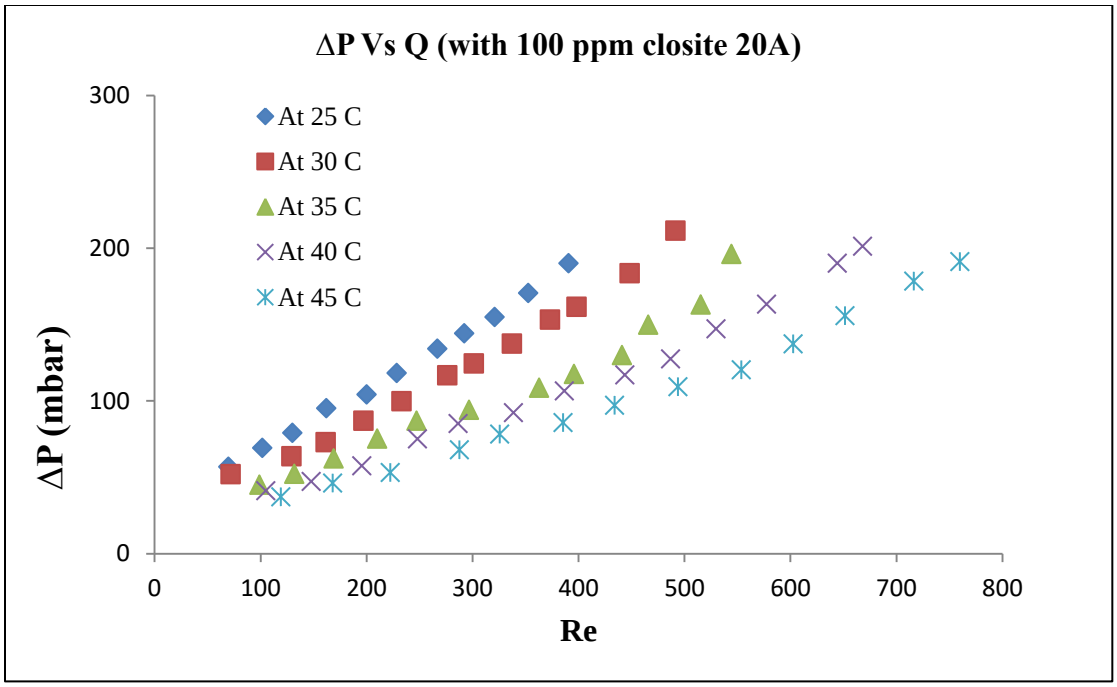


Figure 4-14: The effect of the temperature difference to the Reynolds number (Re) with the emulsified emulsion +100ppm closite 20A

Similar trend can be seen also in the case of emulsified emulsion with cliosite and also it have same justification as the emulsion with only ARMAC-T beside that the cliosite effect. That closite minimize the droplet size of the water inside oil and hence it have a smaller pressure drop values that the emulsion without cliosite.

To clarify the effect of the 100ppm Closite 20A, a comparison was done between the pressure drop when using only the emulsifier agent and the emulsion that containing the emulsifier agent plus the 100ppm closite 20A, at similar operational conditions.

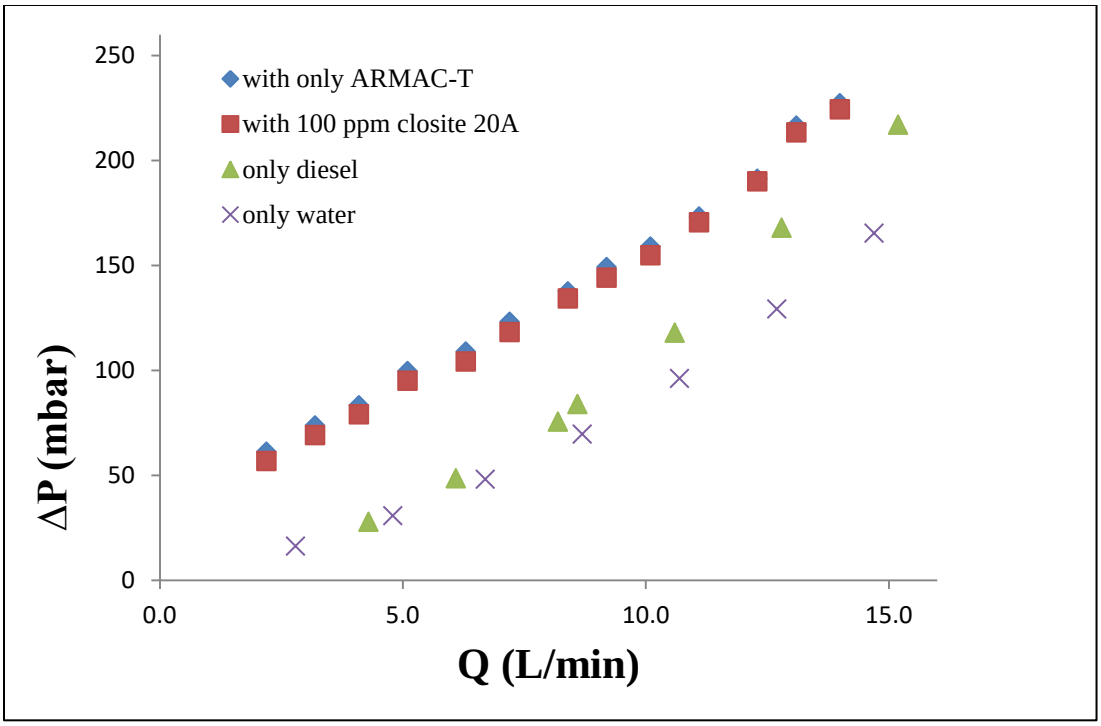


Figure 4-15: The 100ppm closite 20A effect at 25 °C

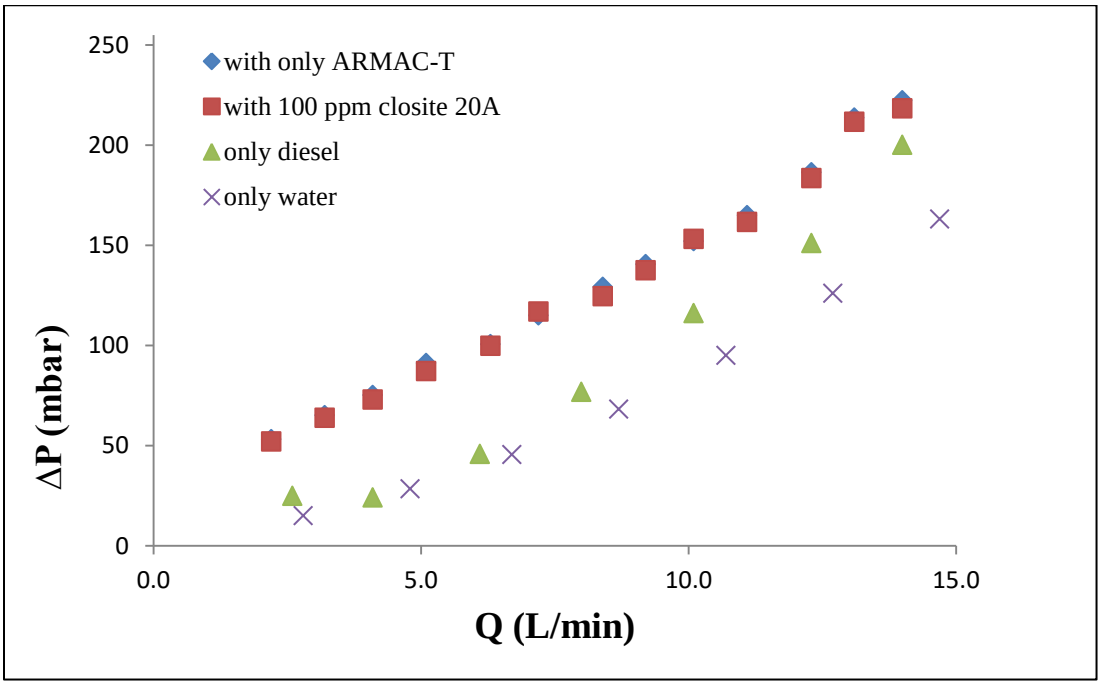


Figure 4-16: The 100ppm closite 20A effect at 30 °C

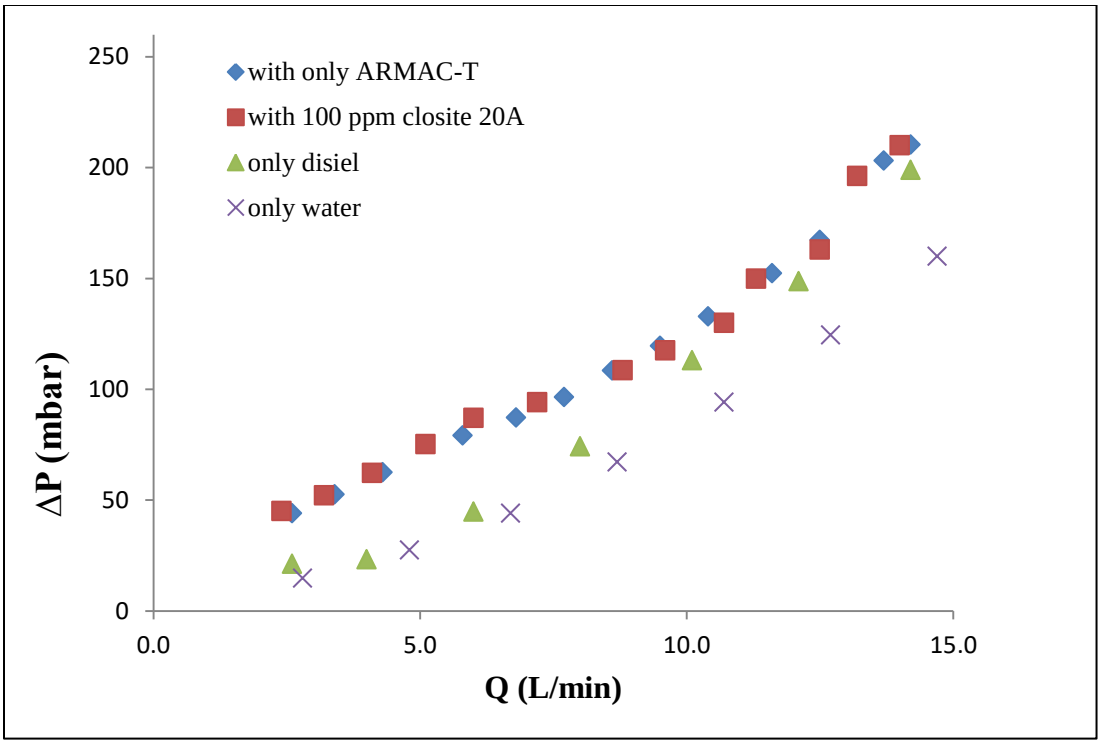


Figure 4-17: The 100ppm closite 20A effect at 35 °C

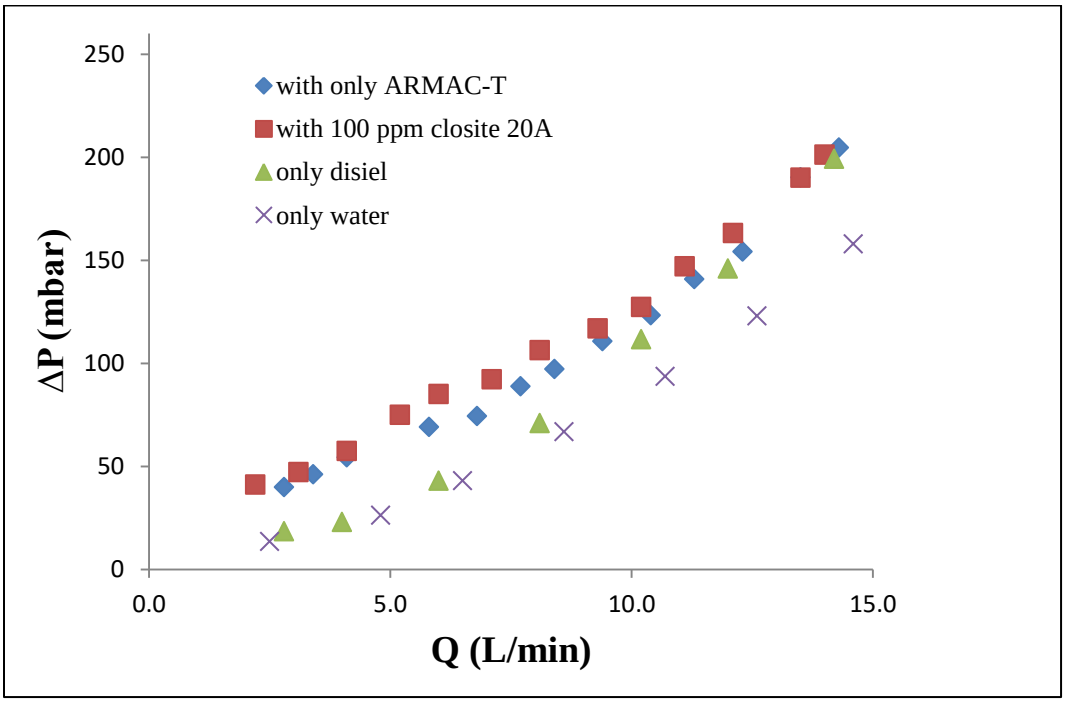


Figure 4-18: The 100ppm closite 20A effect at 40 °C

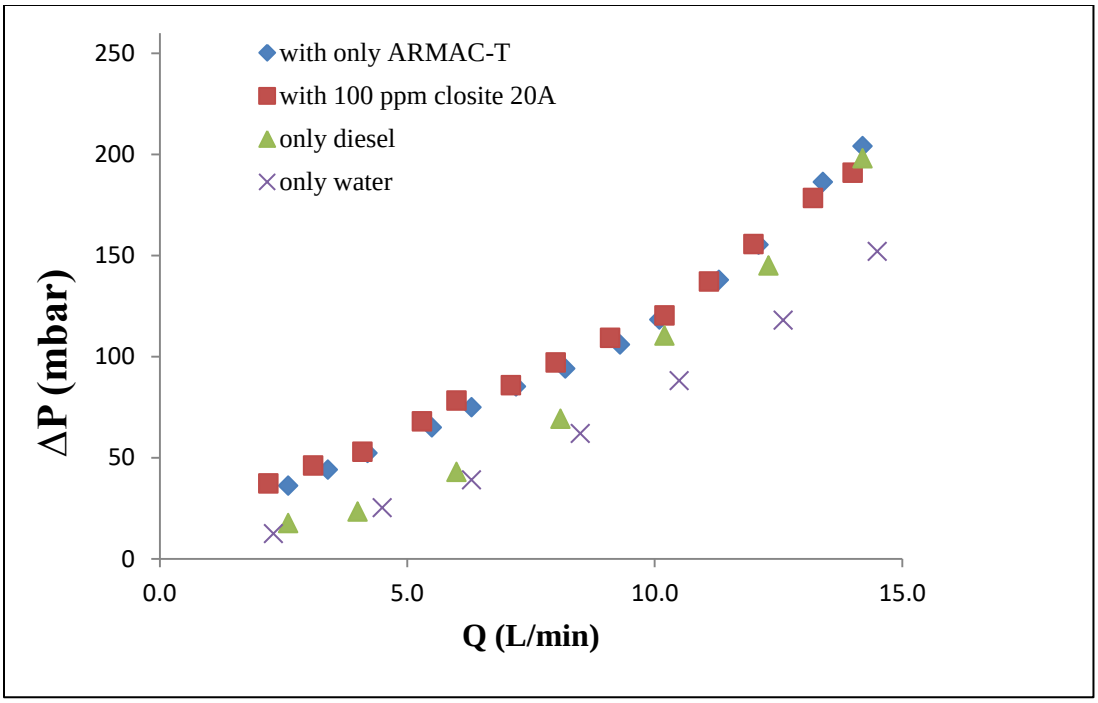


Figure 4-19: The 100ppm closite 20A effect at 45 °C

It can be seen in the figures 4-15 to figure 4-19 that both cases Armact –T and Closite have similar results. At 40 C some differences can be seen. However, at high flow rate all are the same and even similar to pure diesel.

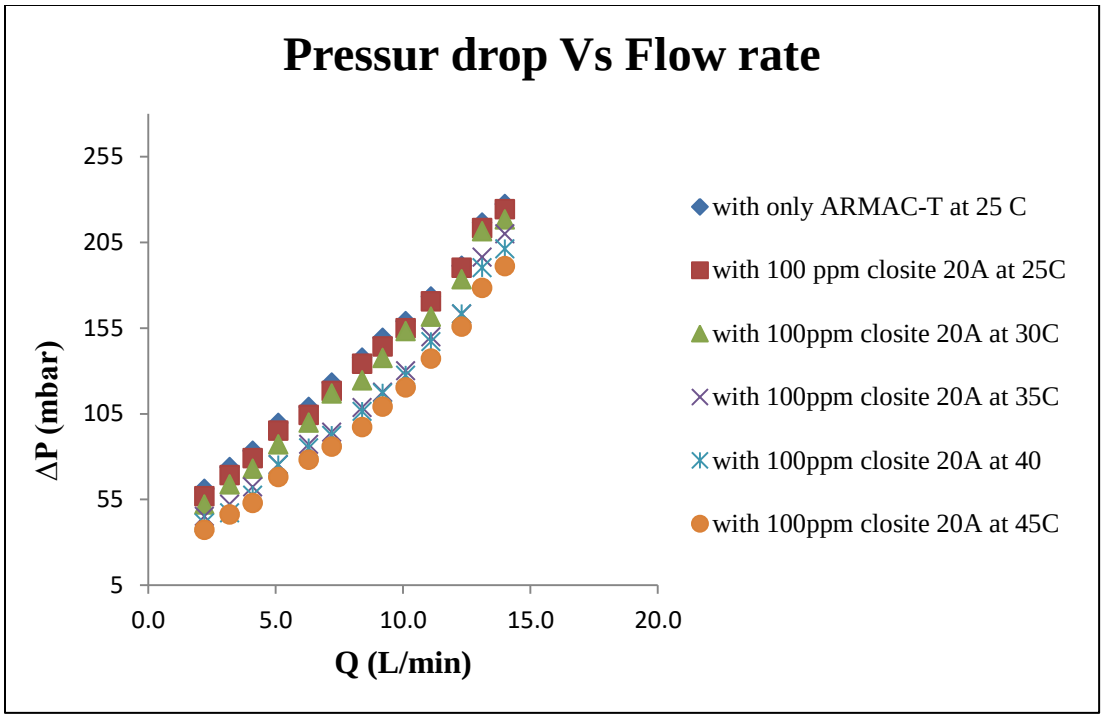


Figure 4-20: The effect of 100ppm closite 20A when compared with the emulsion pressure drop with only ARMAC-T at 25 °C.

Figure 4-20 shows that adding 100ppm of closite 20A to the emulsion at 25 °C has a small effect but after increasing the temperature up to 45 °C, the decrease in the pressure drop can be effective. It can be noticed also that the same previous phenomena in which the difference between the plots of pressure drop starts to decrease at high flow rate. To present the influence of the temperature in more clear way the percentage of deviation between the pressure drop at any temperature is compared with that at 25 C first to the emulsion with only the emulsifier agent and second for the emulsion after adding 100ppm closite 20A. The percentage of pressure drop reduction is defined as follows:

$$div\ \% = \frac{\Delta P_{with\ only\ ARMAC-T@25} - \Delta P_{@T}}{\Delta P_{with\ only\ ARMAC-T@25}} \times 100\%$$

Where

$\Delta P_{@T}$ ≡ represent the pressure drop at any temperature from 30 to 45 °C.

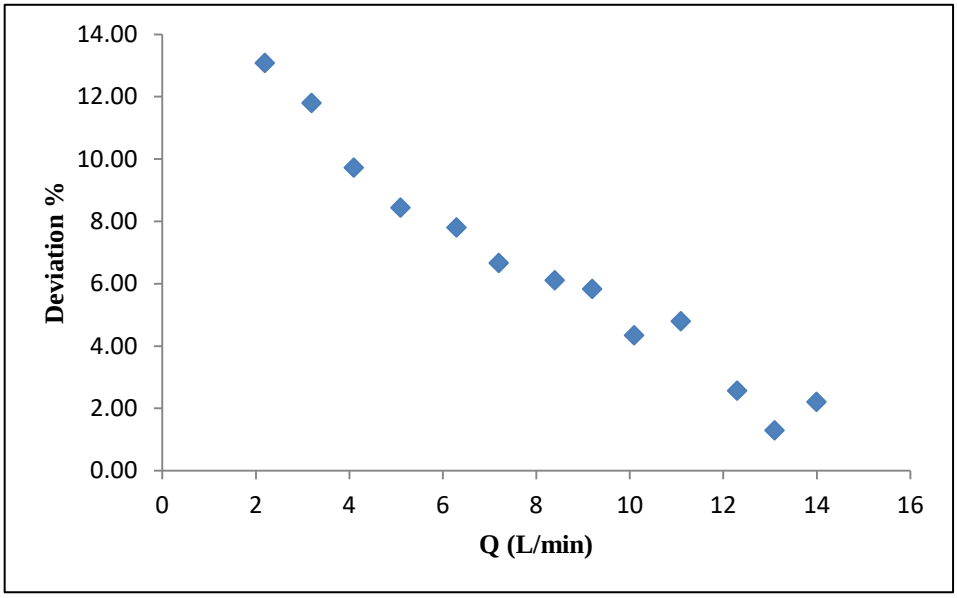


Figure 4-21: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 30 °C.

Figure 4-21 shows that at low flow rates, the deviation is close to 14% and with increasing the flow rate the deviation start decreasing until it reached the lowest pressure drop deviation of 2% approximatly. This figure and the rest of deviation figures clarify the phenomena mentioned earlier, where at high flow rates the pressure drop at different temperatures are about the same.

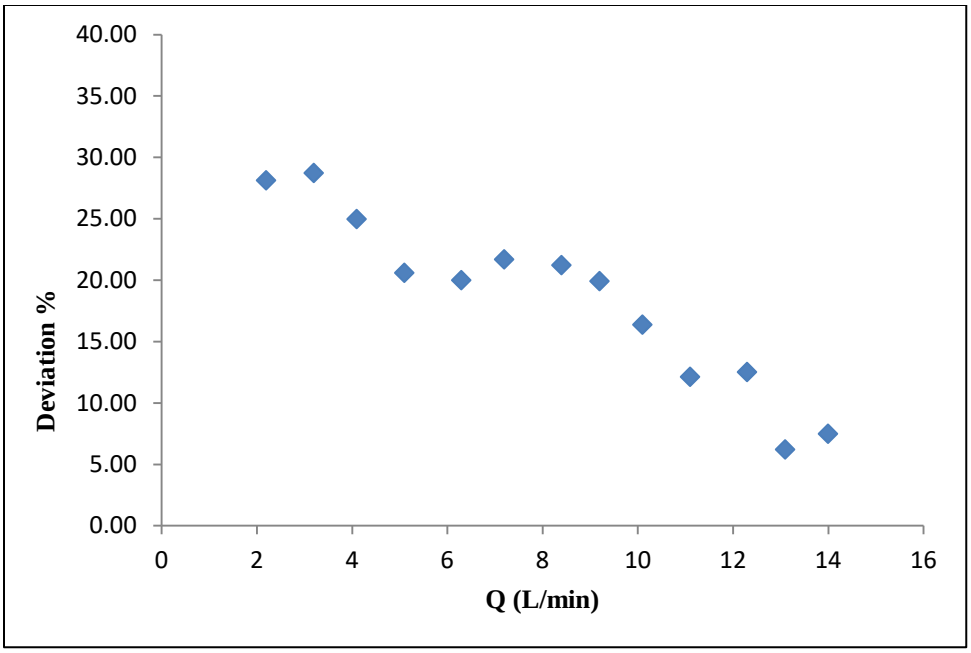


Figure 4-22: The pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 35 °C.

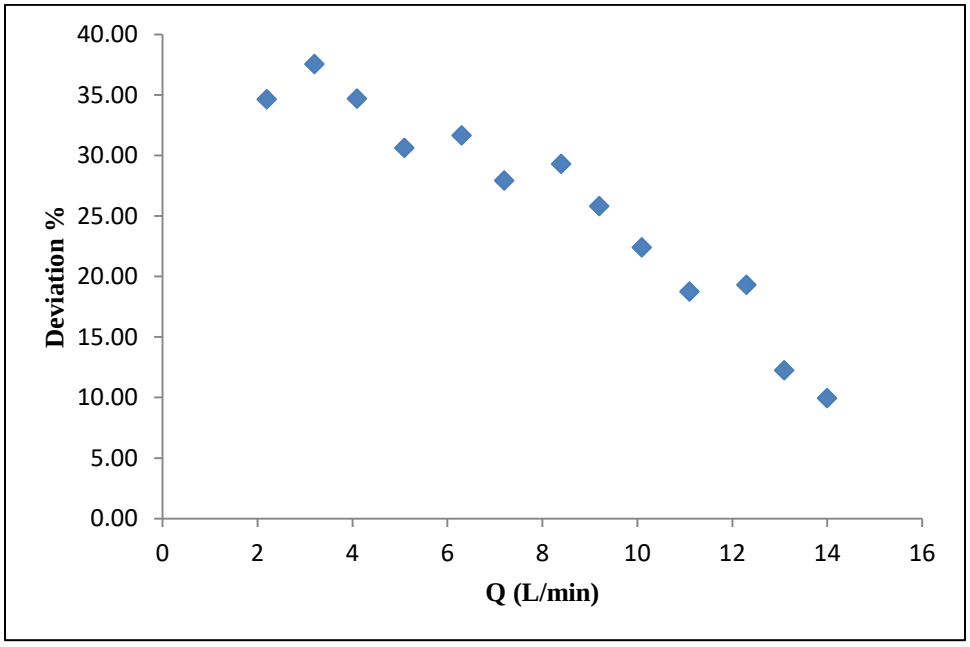


Figure 4-23: The pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 40 °C.

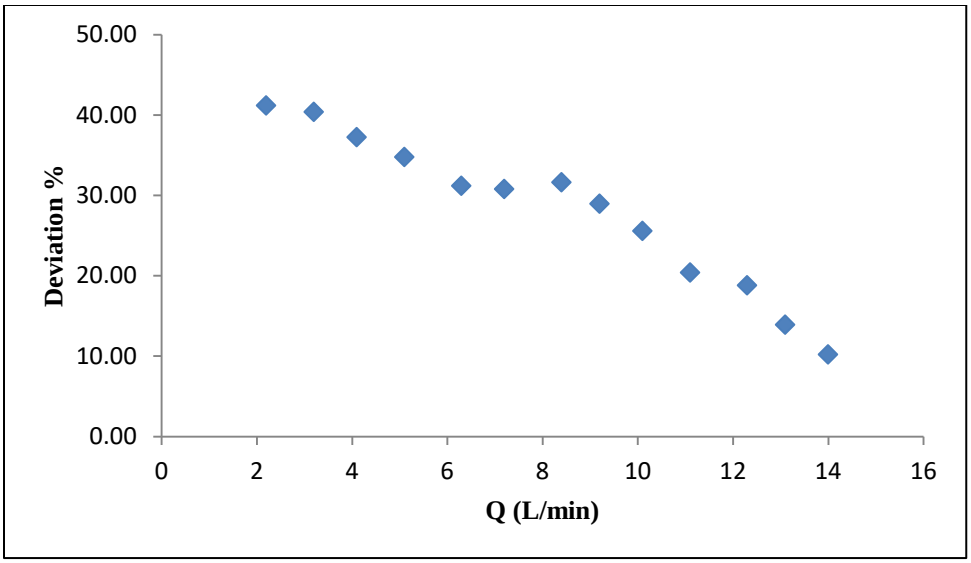


Figure 4-24: The pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 45 °C.

Here it is clear that the pressure drop deviation at the higher temperatures (35, 40 and 45 °C) was increased until it reached about 10% reduction at the highest flow rate for 40 and 45 °C, where it is almost half of the case at 35 °C. This result can be attributed to the shear thinning effect of highly concentrated emulsions.

As mentioned before the deviation of the pressure drop of the emulsified emulsion at 25 °C and the emulsified emulsion with 100ppm closite 20A at different temperatures (25, 30, 35, 40 and 45 °C) are defined below :

$$div\ \% = \frac{\Delta P_{with\ only\ ARMAC-T@25} - \Delta P_{with\ 100ppm\ closite\ 20A@T}}{\Delta P_{with\ only\ ARMAC-T@25}} \times 100\%$$

Where

$\Delta P_{with\ 100ppm\ closite\ 20A@T}$= represent the pressure drop at any teperature from 25 to 45 °C.

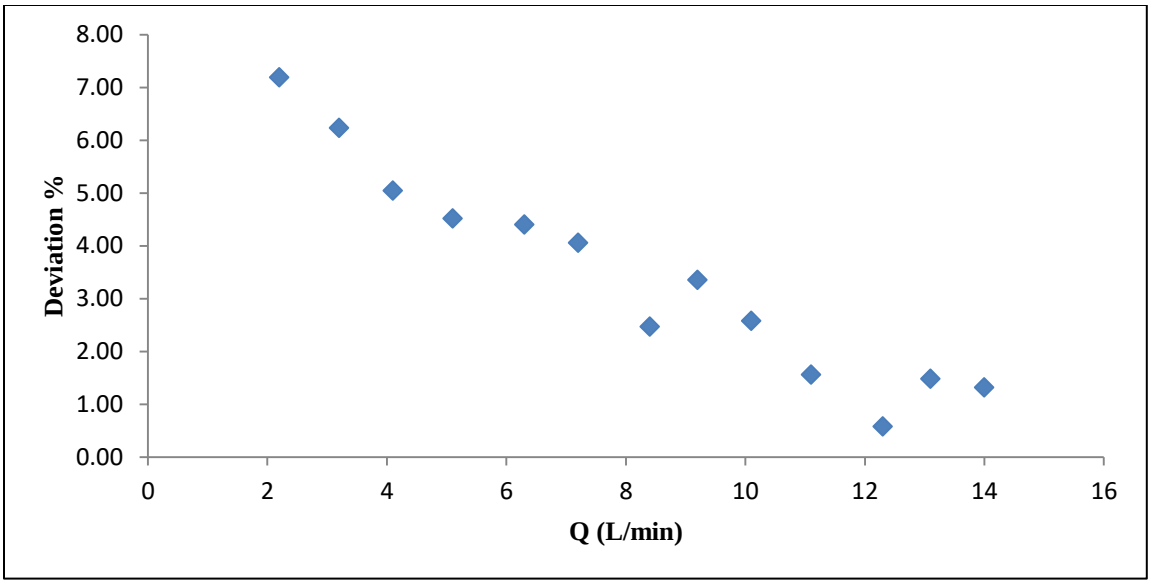


Figure 4-25: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 25 °C.

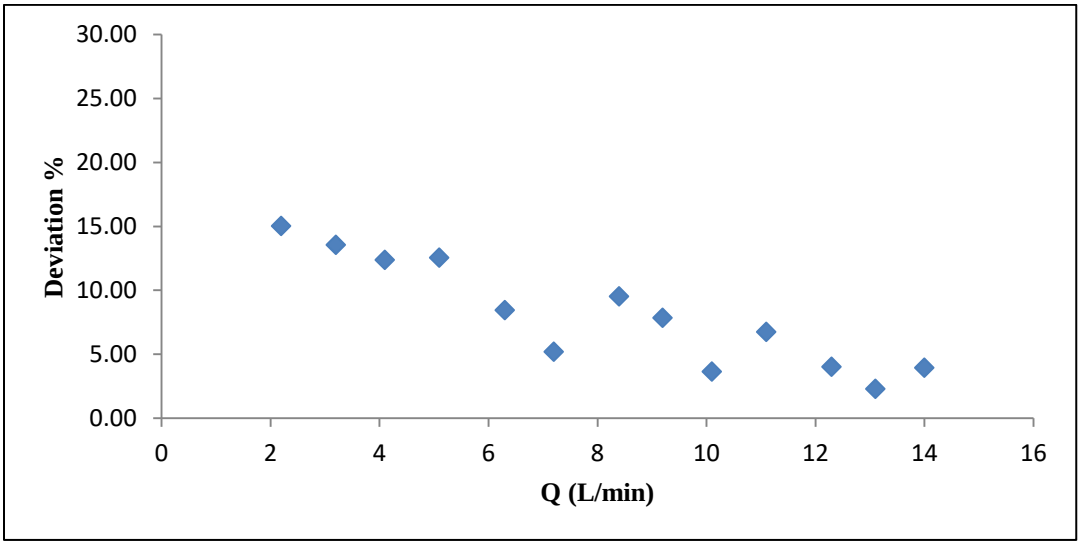


Figure 4-26: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 30 °C.

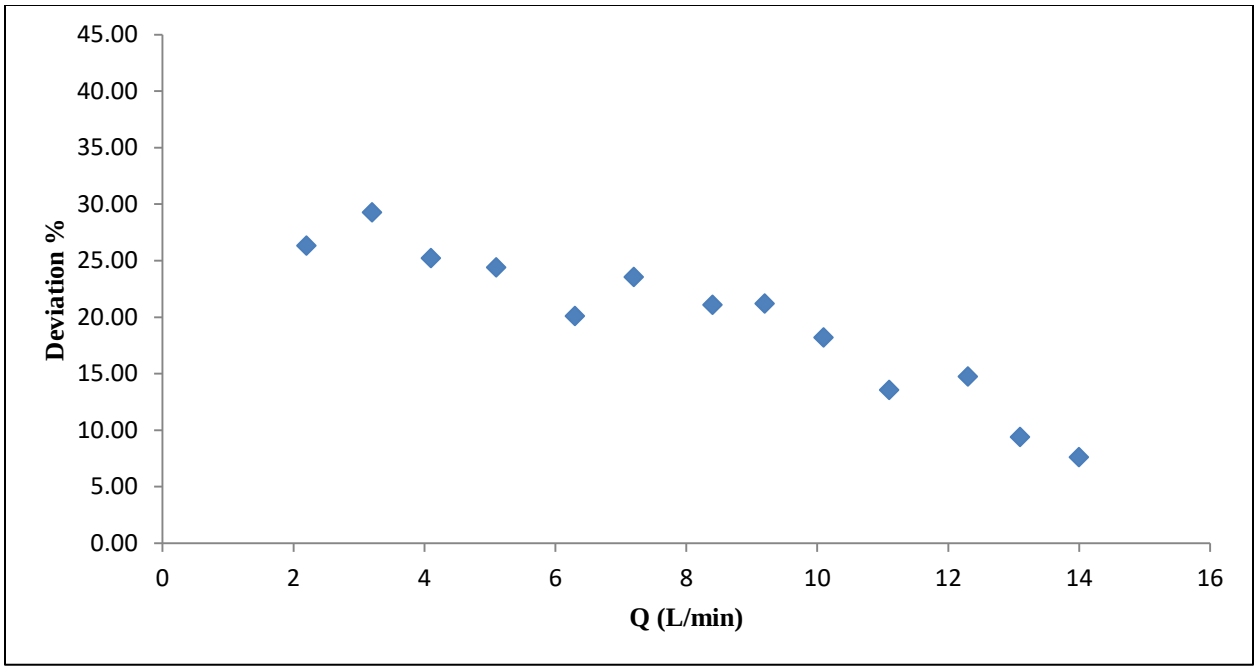


Figure 4-27: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 35 °C.

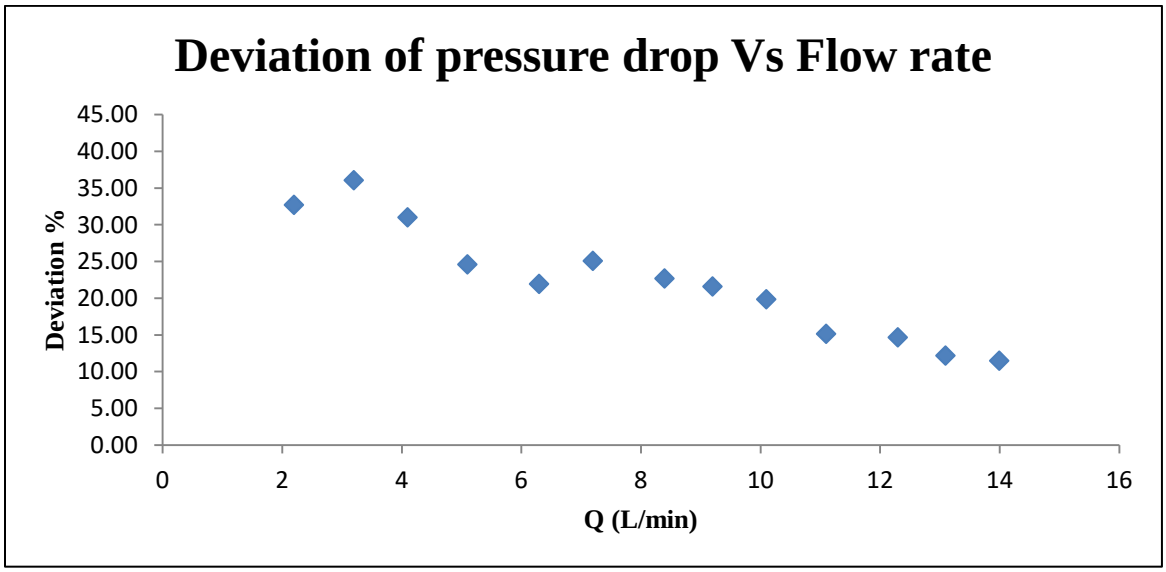


Figure 4-28: The pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 40 °C.

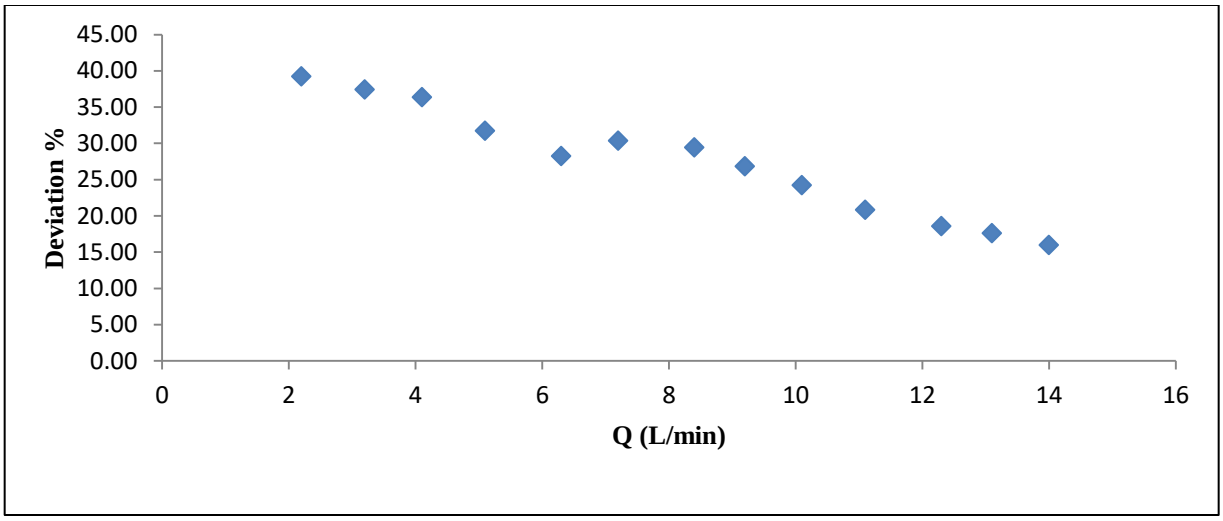


Figure 4-29: The pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 45 °C.

The figures shows that the decrease in the pressure drop percentage is quite small for 25 and 30°C at high flow rates, where it then starts increasing after the temperature reaches 35 °C to reach 7% reduction in the pressure drop. The highest pressure drop percentage was at the 40 and 45°C (10 and 15 % respectively). The 100ppm closite 20A showed a great pressure drop reducer at the temperature of 45 °C where the percentage of reduction increased by 5% after adding 100ppm closite 20A.

4.2 50/50, w/o emulsion:

4.2.1 Stability

Similar to the 70/30, w/o emulsion, stability tests have been done for the emulsion (50/50, w/o emulsions). Samples of the respective emulsion was kept inside an oven at a temperature of 45 °C and monitored with time. The percentage of the emulsion remaining volume fraction was reported. The results of the two emulsions are listed below one test was for emulsion with only the emulsifier (ARMAC-T) and other with (ARMAC_T + 100ppm closite 20A):

4.2.2 Stability of 50/50 emulsion with only emulsifier (ARMAC-T):

The stability test for this emulsion given below:

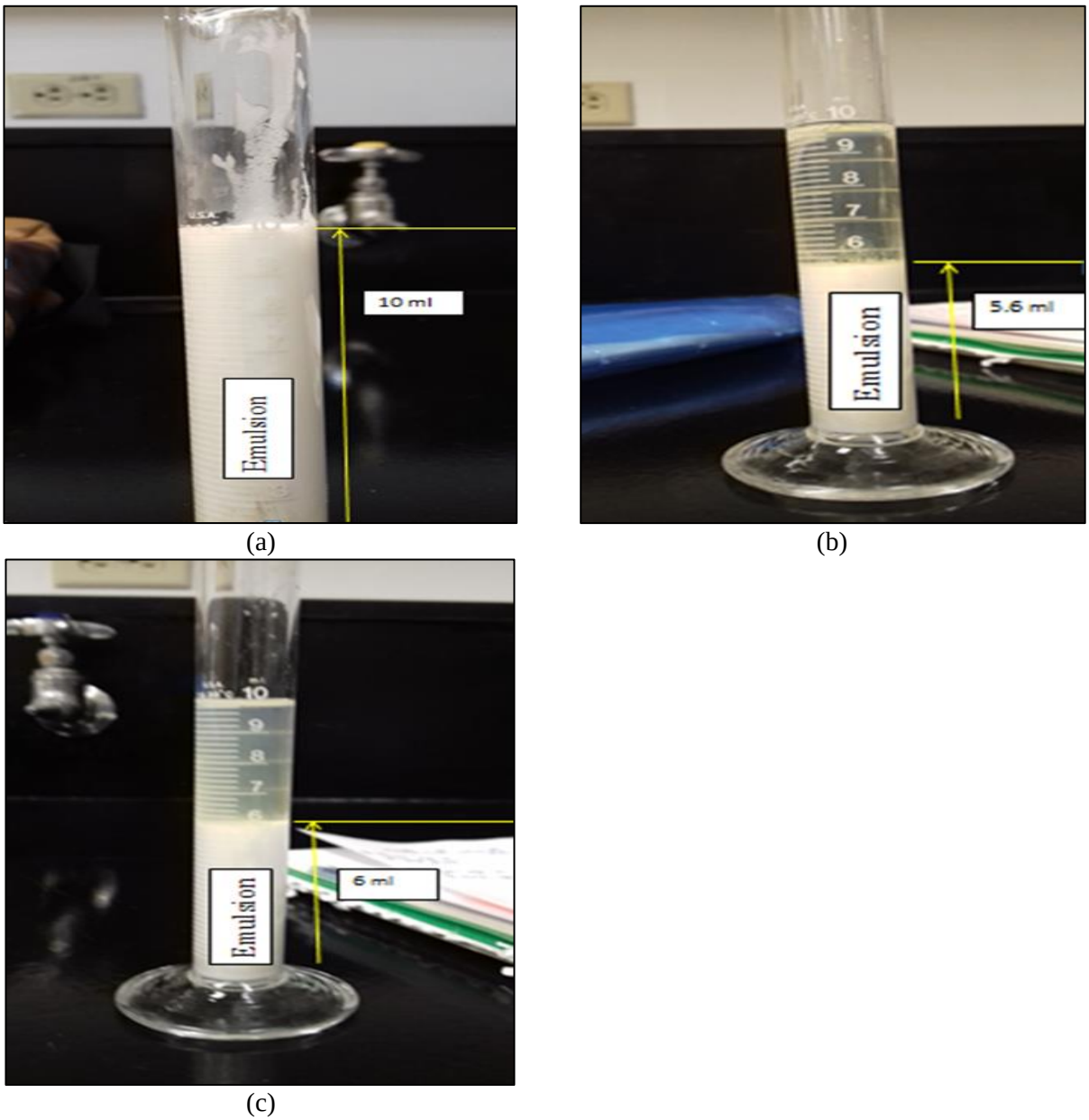


Figure 4-30: The emulsion (with only ARMAC-T) volume after :(a) mixing, (b) 14 hours and (c) 28 hours

The detailed emulsion volume for 28 hours is shown in Table 4-8:

Table 4-5: The emulsified emulsion stability with time:

Time (hours)	Emulsion vol (ml)
0	10.00
4	6.00
14	5.60
28	5.60

The result above shows that after 28 hours at a temperature of 45 °C, the separation was only 4.4 ml with a separation percentage of 41% after 7 hours which is the targeted time.

Fig (4-31) shows the trend that describes the behavior of this emulsion with time:

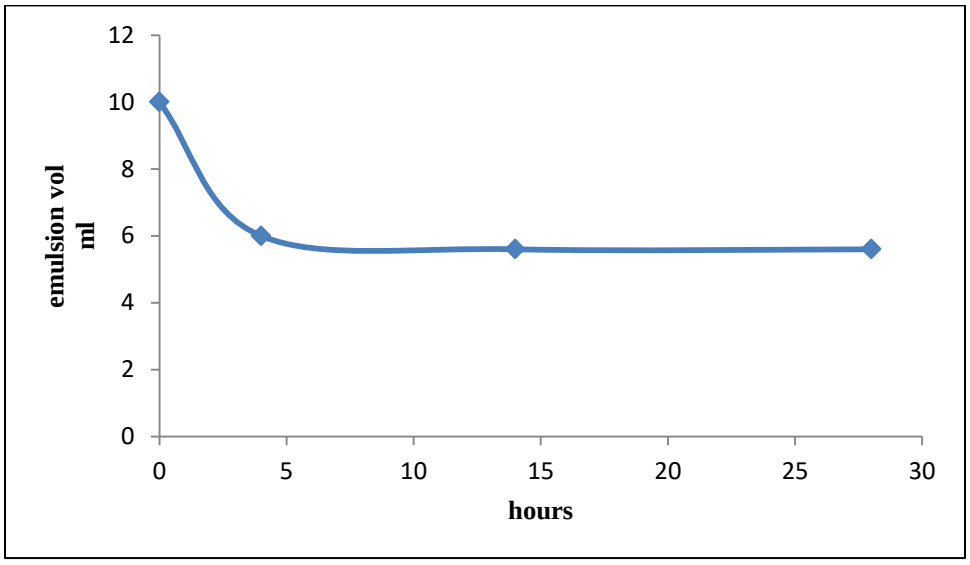


Figure 4-31: Shows the emulsion volume through 28 hours

Moreover, a dilution test was performed to identify the emulsion continuous (external) phase. In this test, one droplet of the formed emulsion is injected in an oil or water pure phase. If droplet disperses, emulsion continuous (external) phase is the same as the used fluid for the test and vice versa.

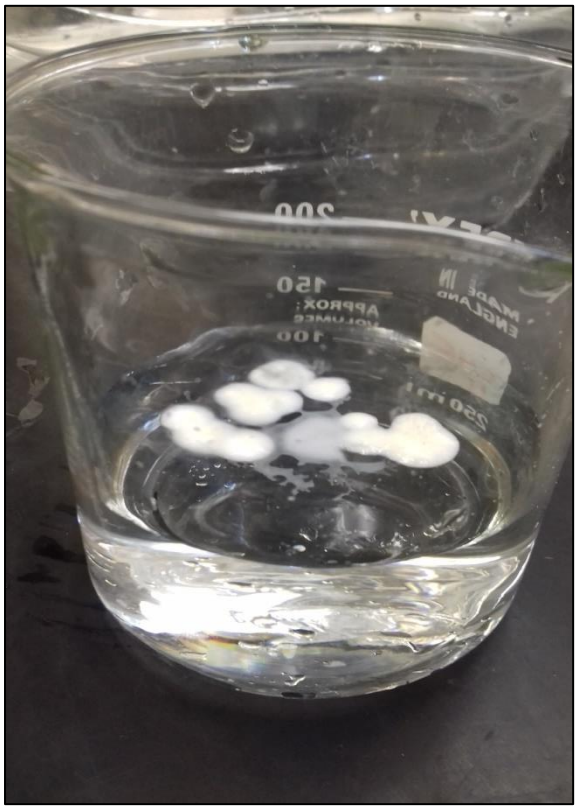


Figure 4-32: The oily outer phase emulsion flouts in water

4.2.3 The emulsion with emulsifier (ARMAC-T) and 100ppm closite 20A:

The emulsion is the same as the one with only ARMAC-T but here we add 100ppm closite 20A gradually to the emulsion. In this case also the emulsion was left inside a 45°C oven and then the data collected for the separated oil volume fraction.

The stability test for this emulsion is given below in Figure 4-33:

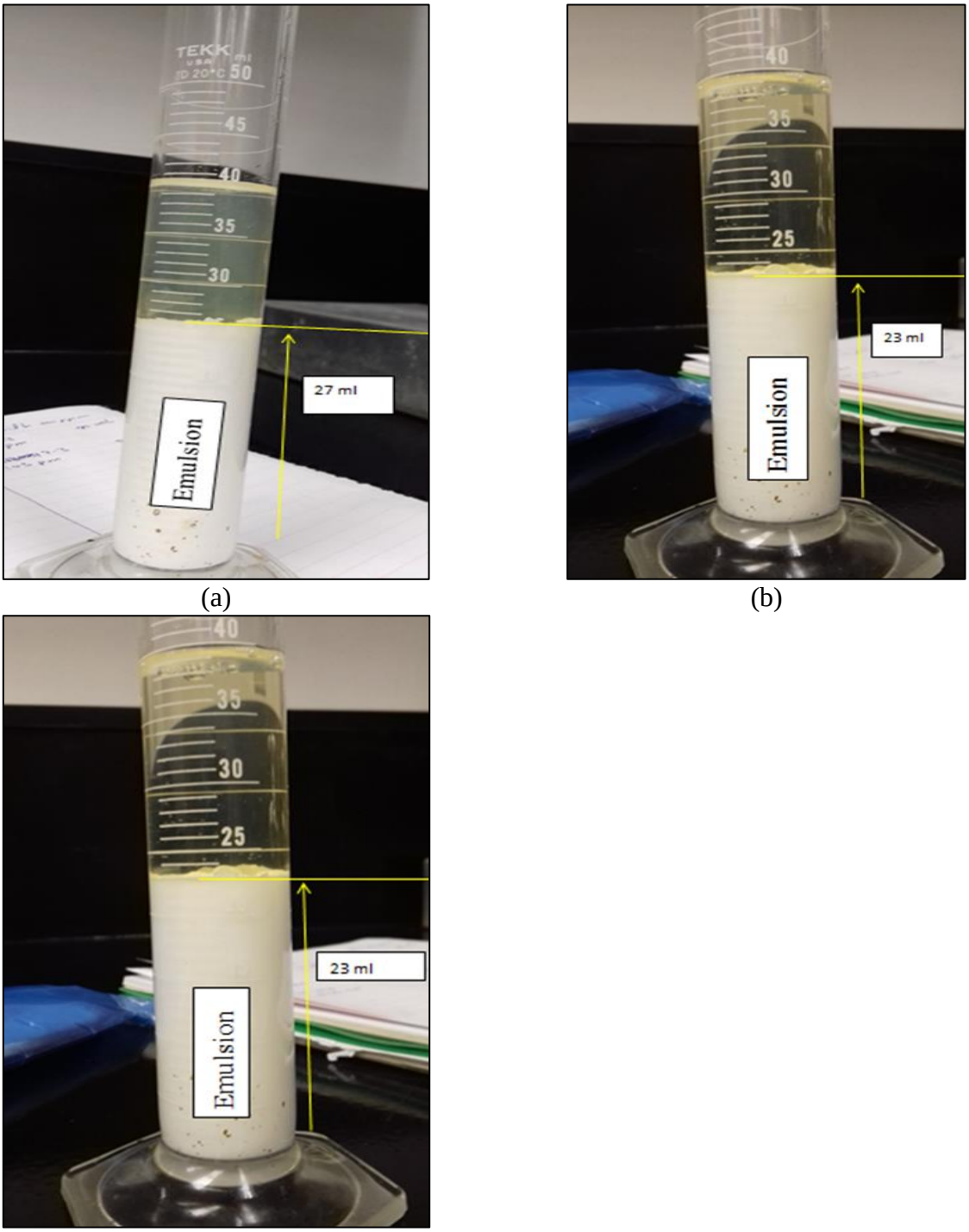


Figure 4-33: The emulsified emulsion +100ppm closite 20A volume after: (a) 16 hours , (b) 25 hours and (c) 36 hours

The detailed emulsion volume for 36 hours is shown in Table 4-10:

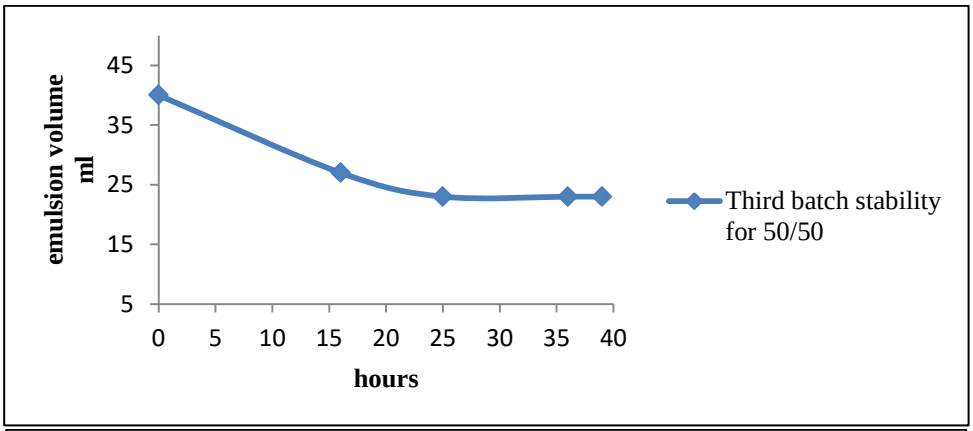
Table 4-6: The stability of the emulsified emulsion with 100ppm closite 20A:

Time (hours)	Emulsion vol(ml)
0	40
16	27
25	23
36	23

The separation results show that after 16 hours the separation of the oil was 16 ml with a separation percentage of 49% although only the targeted time is 6 hours.

The figure below describes the behavior of this emulsion during 36 hours for 50/50, w/o emulsion:

a)



b)

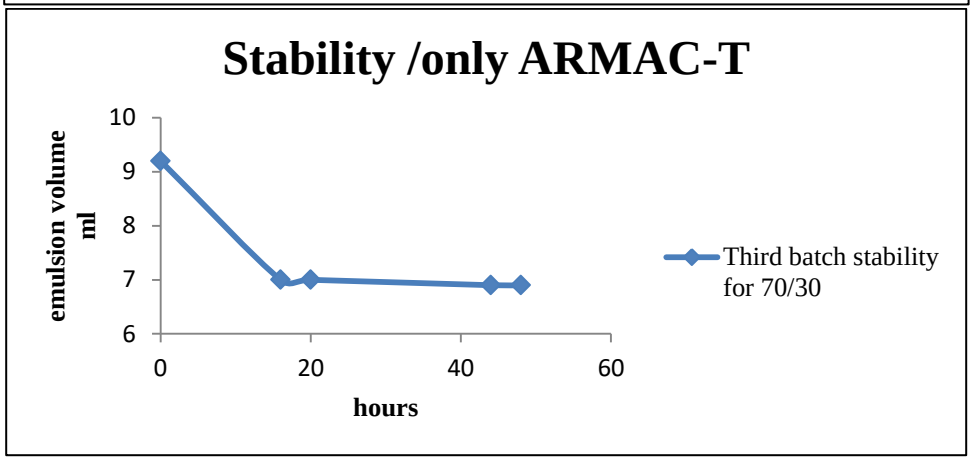


Figure 4-34: Shows the emulsion volume through 48 hours for a)50/50, b)70/30, w/o emulsion with 100ppm closite 20A.

4.2.4 Rheology

All tests have been done by rheometer device (TA, Discovery HR-3, Hybrid rheometer) for the viscosity estimation while the density was obtained using Anton Paar-DMA 4500M density meter. The tests done for two samples, the first one with only emulsifier and the other is with 100ppm organoclay beside the emulsifier. The density and the dynamic viscosity are the two emulsion properties of interest in the present application.

4.2.5 The rheology test results for emulsion with only emulsifier agent (ARMAC-T):

All rheological measurements were conducted using the TA, Discovery HR-3, Hybrid rheometer. The results are obtained directly through a computer at different temperatures.

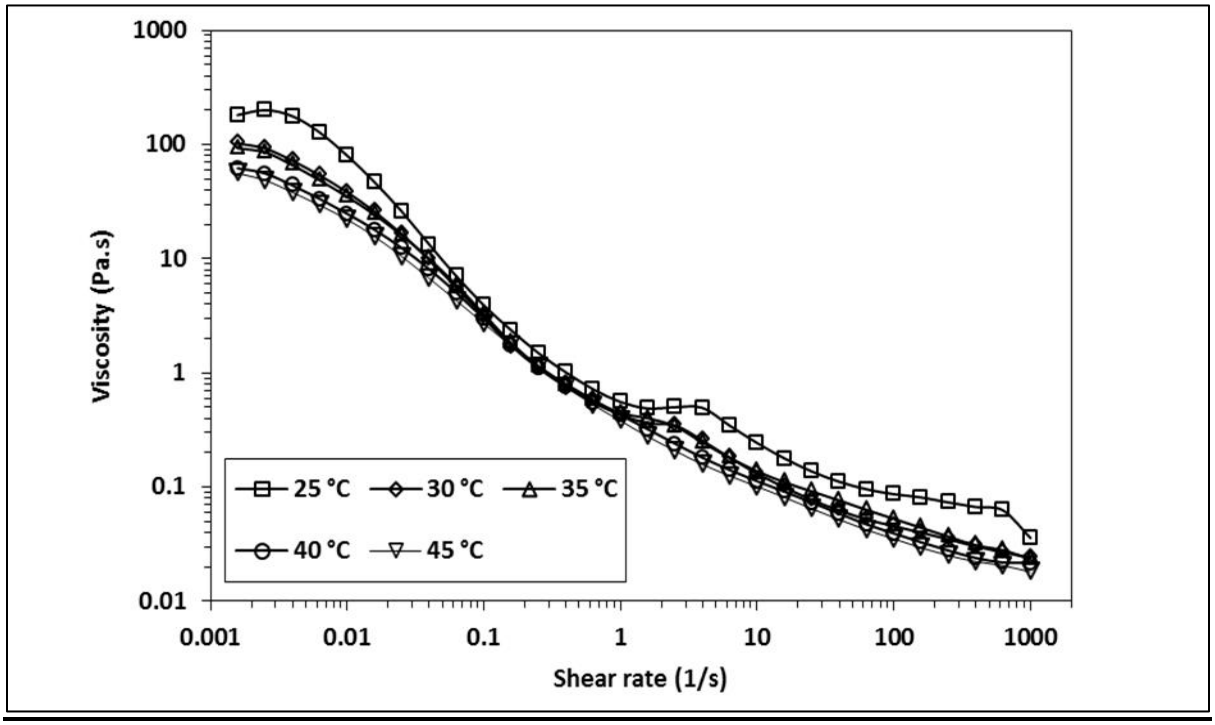


Figure 4-35: The dynamic viscosity with different temperatures

The viscosity at 25, 30, 35, 35 and 40 °C is the temperature range of interest in this study and the pressure drop results will be conducted at these temperatures. The density and dynamic viscosity values at the interested emulsion temperature values are shown in Table 3.

Table 4-7: Density and the dynamic viscosity of emulsion at different temperatures:

T (°C)	ρ, emulsion (Kg/m^3)	μ, emulsion (Pa.s)
25	951.125	0.0370
30	951.070	0.0239
35	945.077	0.0230
40	939.740	0.0208
45	939.451	0.0190

Increasing temperature from 25 to 45 °C, only decreasing the density by about 1.2% from the first value. But it is obvious that the increasing of temperature affect the dynamic viscosity significantly. The reduction here is because of the same reason of the 70/30, w/o emulsion that the temperature works to break the bonds between molecules and hence a reduction on the viscosity happens.

4.2.6 The rheology test results for emulsion with emulsifier agent (ARMAC-T) and organoclay (100ppm closite 20A):

The rheological procedure is the same for both cases (with and without closite). After adding 100ppm of the closite 20A the emulsion subjected to the rheological tests and the results is shown below.

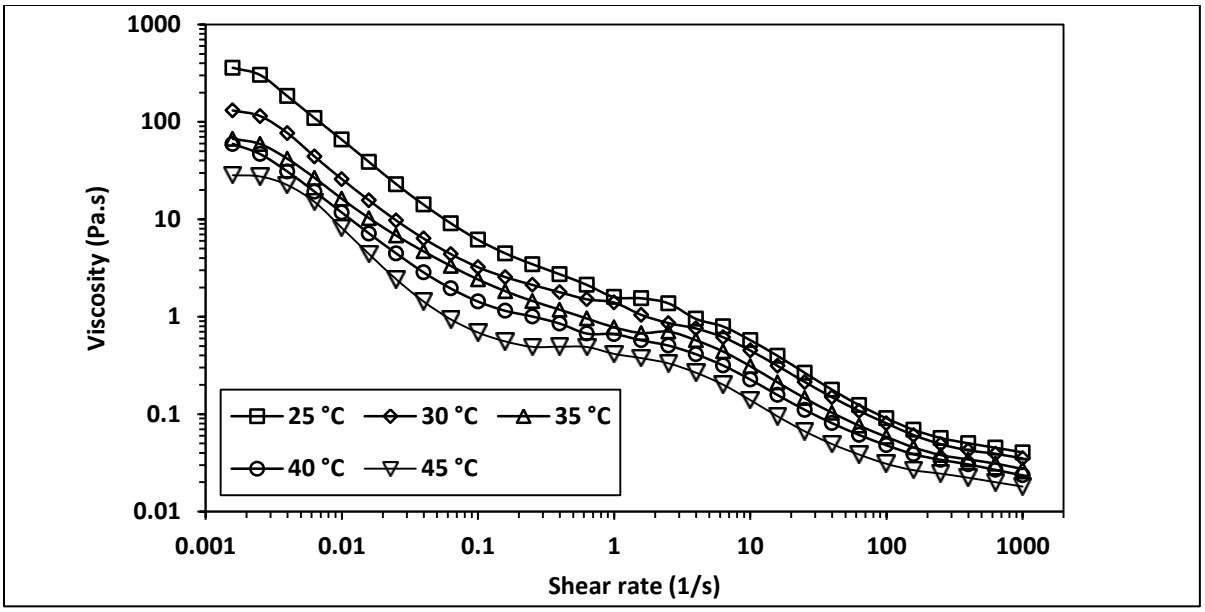


Figure 4-36: The dynamic viscosity of the emulsion with 100ppm closite 20A with different temperatures

Below is the density and dynamic viscosity values that will be used in experiments.

Table 4-8: The density and the dynamic viscosity with different temperatures for the emulsion with 100ppm closite 20A:

T (°C)	ρ, emulsion (Kg/m^3)	μ, emulsion (Pa.s)
25	971.68	0.05574
30	966.54	0.05478
35	964.40	0.04775
40	961.70	0.04093
45	958.80	0.03578

It is clear that adding 100ppm of the closite 20A to the emulsion affected firstly the density (the density is higher than the case without closite) and secondly, the closite affects the variation of the density with increasing the temperature.

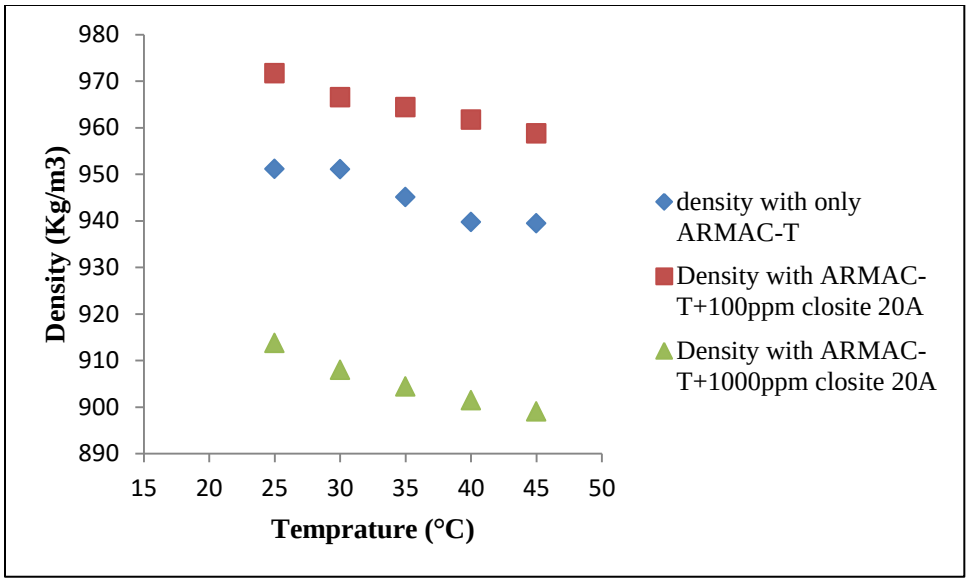


Figure 4-37: The density variation with temperature

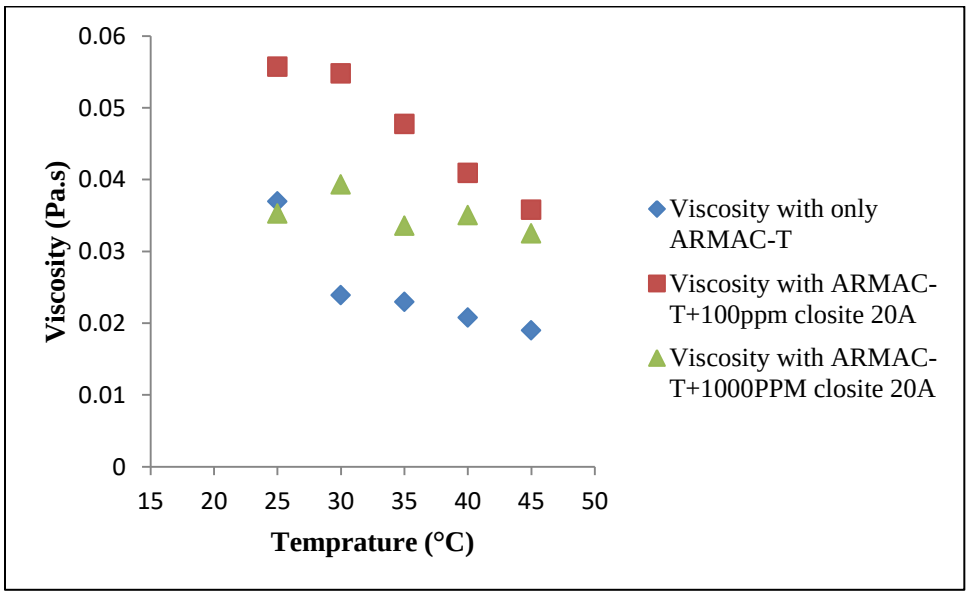


Figure 4-38: The viscosity variation with temperature

Here it is clear that the viscosity of the emulsion with 100ppm is greater than that of 1000ppm and that because adding cloisite decreases the droplet size of the water and hence the viscosity.

4.2.7 Pressure drop variation for the 50/50, w/o emulsion

To investigate the effect of temperature on the variation of pressure drop for the 50/50, w/o emulsion, second experiment had been conducted at different emulsion flow rate. Brine with 2 wt% NaCl (20 kppm) was used as an aqueous phase. After preparing such emulsions, stability tests were carried out using bottle test, by monitoring phase separation with time. Also, the rheology tests were held at the same time. The same procedure was performed for after adding the organoclay to the emulsion as that for the only emulsifier mentioned earlier. Emulsion type and conductivity tests were conducted by performing dilution tests and conductivity measurement, respectively. The emulsion conductivity test was conducted under static conditions after preparing the emulsion by using a conductivity meter. All of the tested emulsions were W/O with a conductivity of 0 V, which was confirmed by the dilution tests.

The pressure drop of all prepared surfactant-stabilized W/O emulsions were measured at different flow rates taken along 1.5m section of the stainless steel pipeline. All measurements were conducted at steady-state conditions. The emulsion temperature was changed from 25 to 45 °C.

Pressure drop measurement results for emulsion flow in pipe are presented in the figures below:

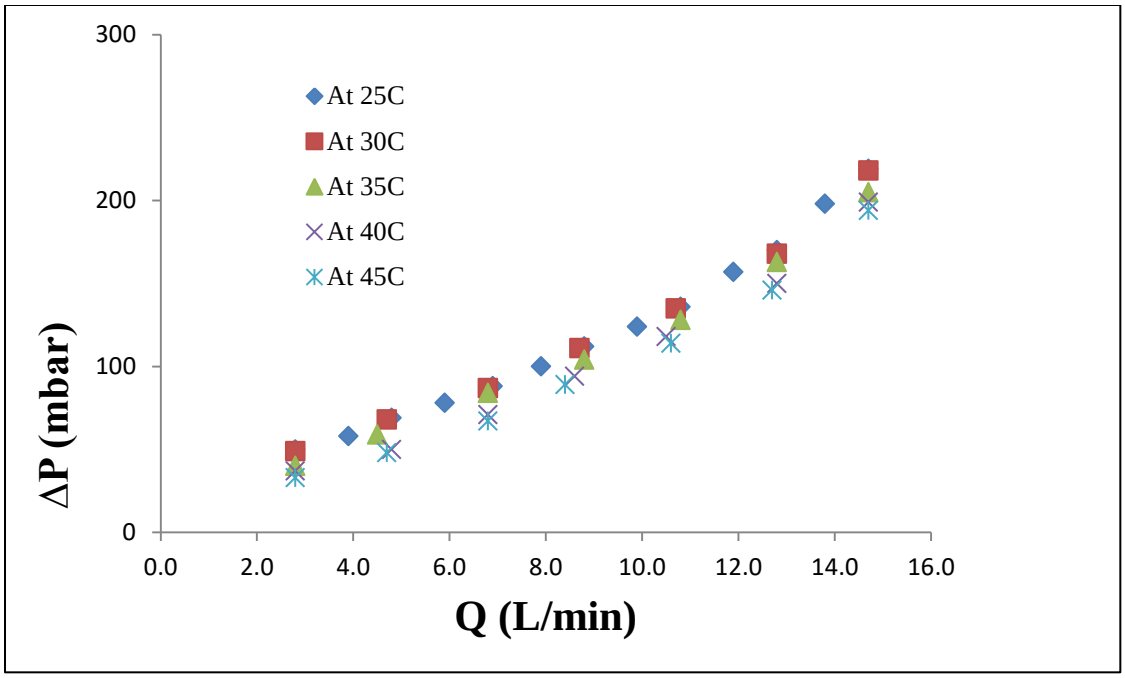


Figure 4-39: Pressure drop variation with emulsion flow rate at different temperature of the emulsified emulsion (only ARMAC-T)

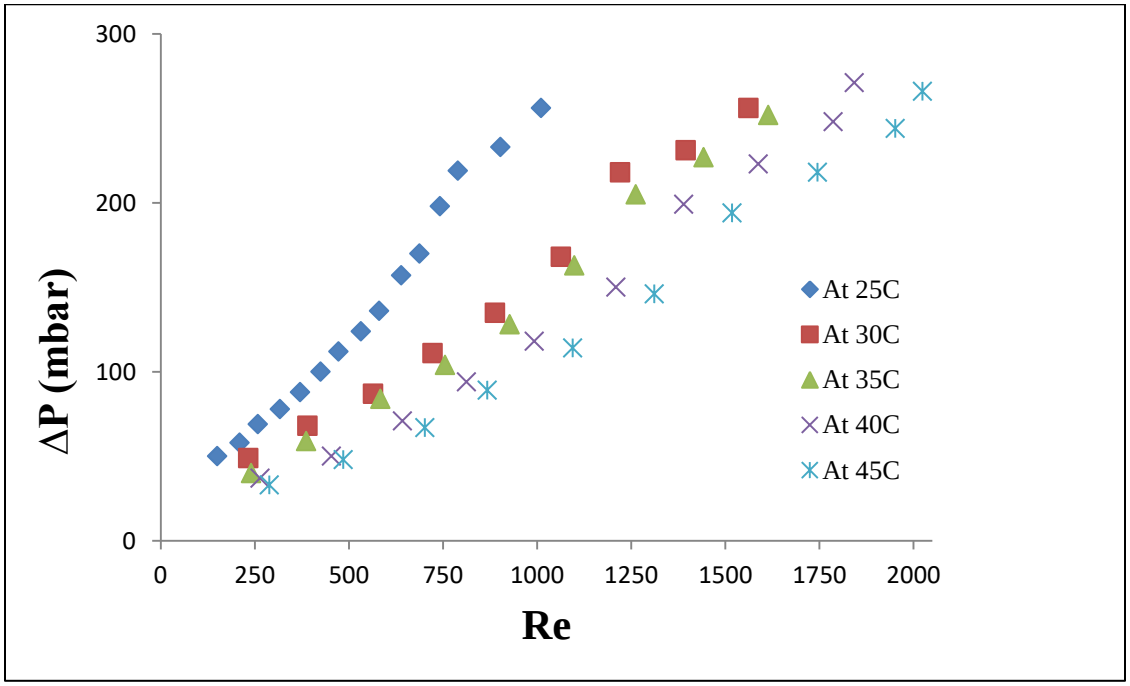


Figure 4-40: Pressure drop variation with emulsion Reynolds number (Re) at different temperature of the emulsified emulsion (only ARMAC-T)

The figure above shows the effect of temperature variation on the pressure drop at different flow rates. Increasing the temperature lead to a decrease in the pressure drop of the emulsion. It seems that at high and low flow rates the pressure drop curves get closer values.

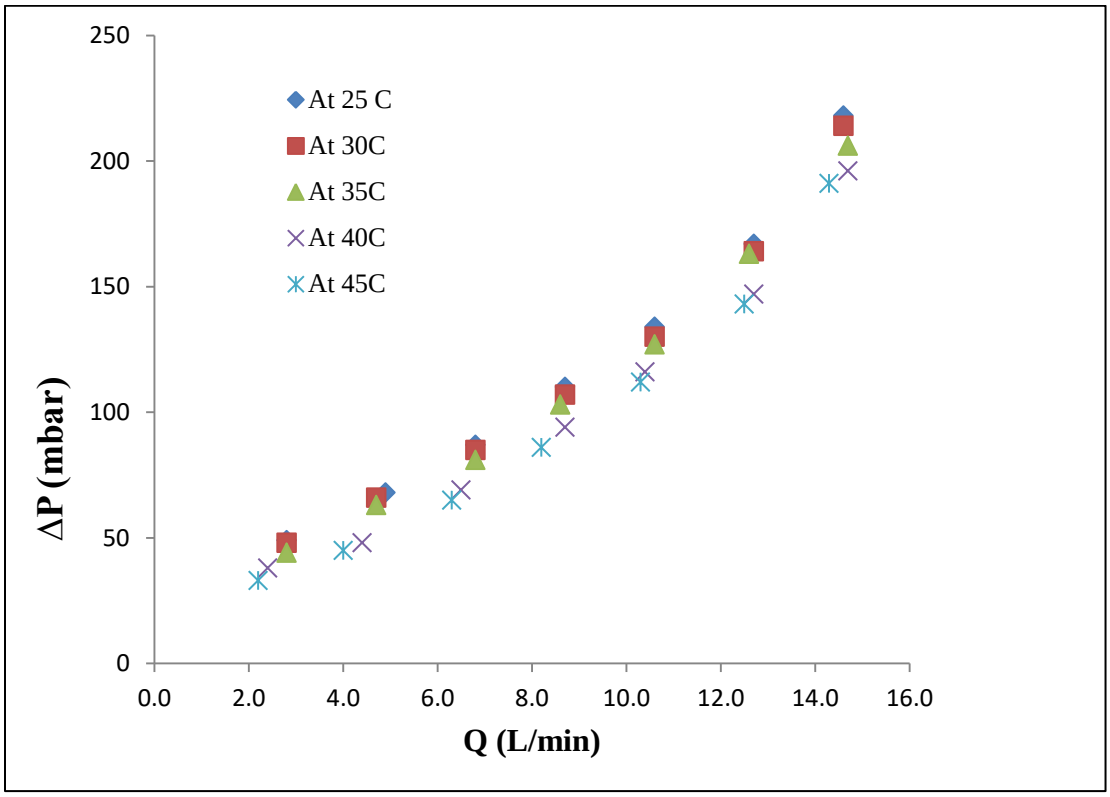


Figure 4-41: The effect of the temperature difference with the emulsified emulsion and 100ppm closite 20A

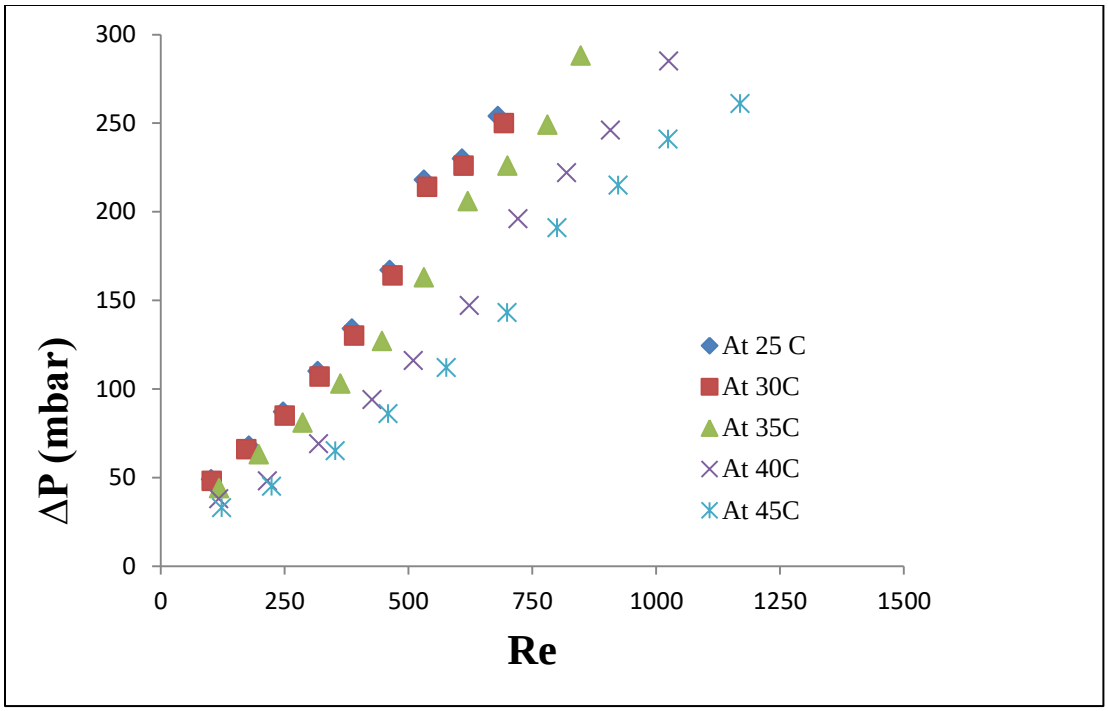


Figure 4-42: The effect of the temperature difference to the Reynolds number (Re) with the emulsified emulsion +100ppm closite 20A

Similar trend can be seen also in the case of emulsified emulsion with closite.

To get the effect of the 100ppm Closite 20A, a comparison was done between the pressure drop when using only the emulsifier agent and the emulsion that containing the emulsifier agent plus the 100ppm closite 20A, at similar operational conditions.

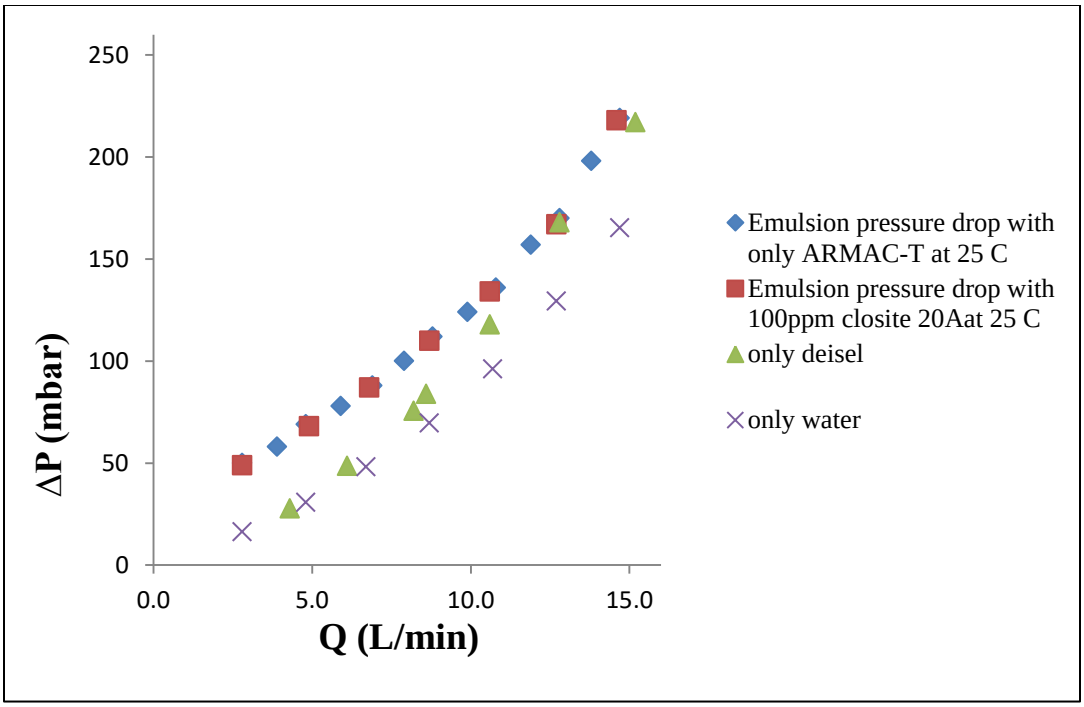


Figure 4-43: The 100ppm cloisite 20A effect at 25 °C

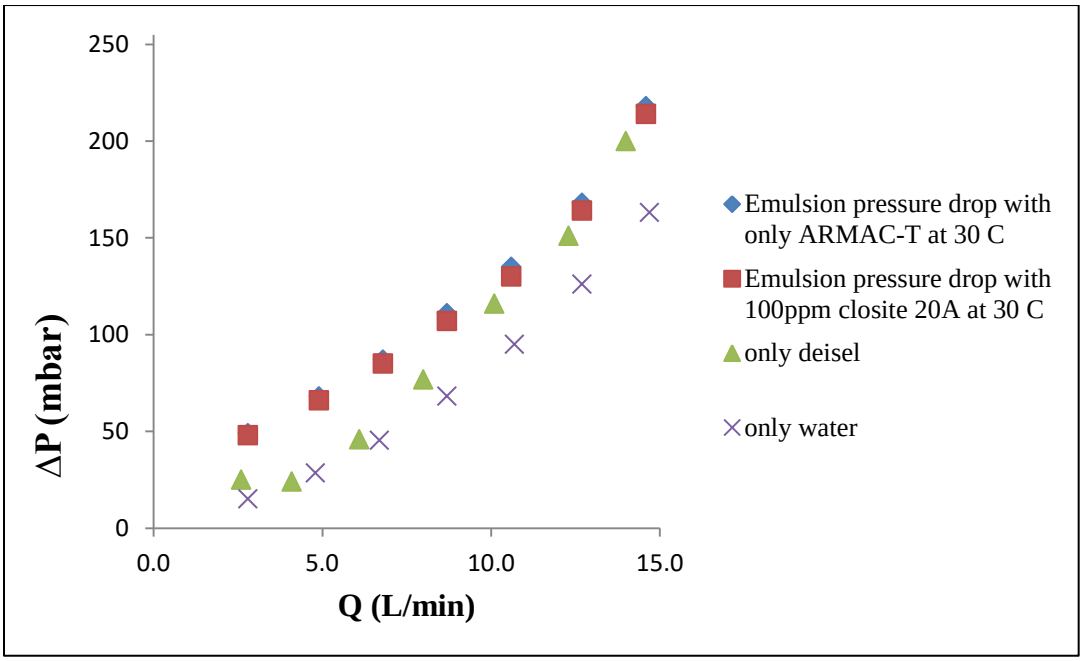


Figure 4-44: The 100ppm cloisite 20A effect at 30 °C

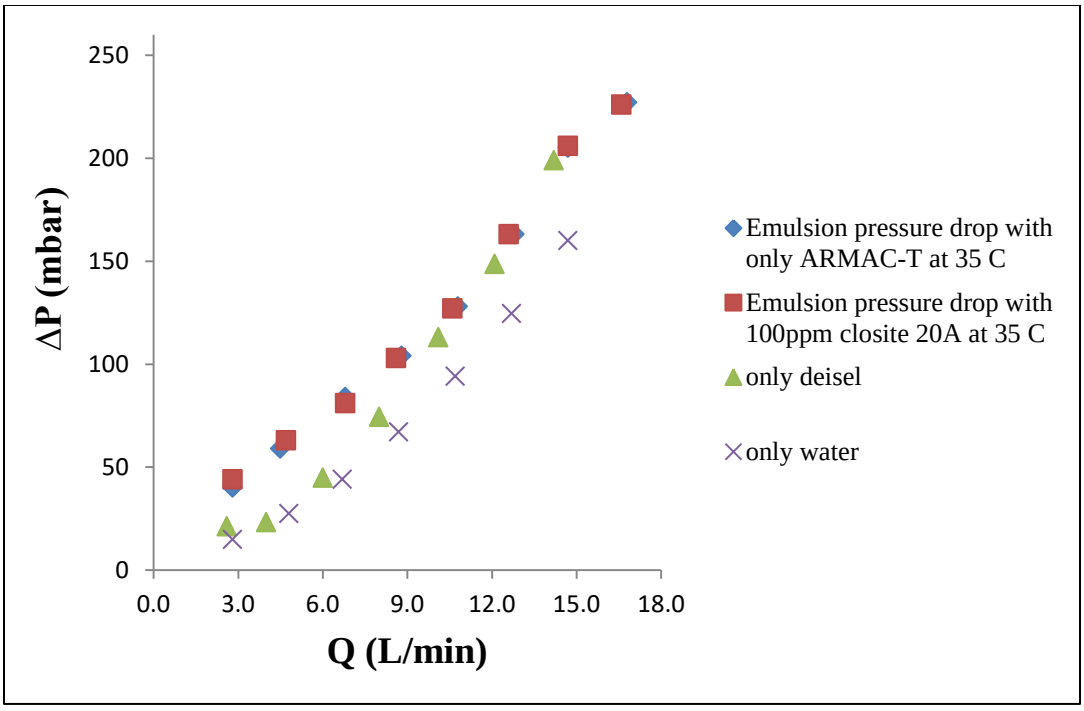


Figure 4-45: The 100ppm cloisite 20A effect at 35 °C

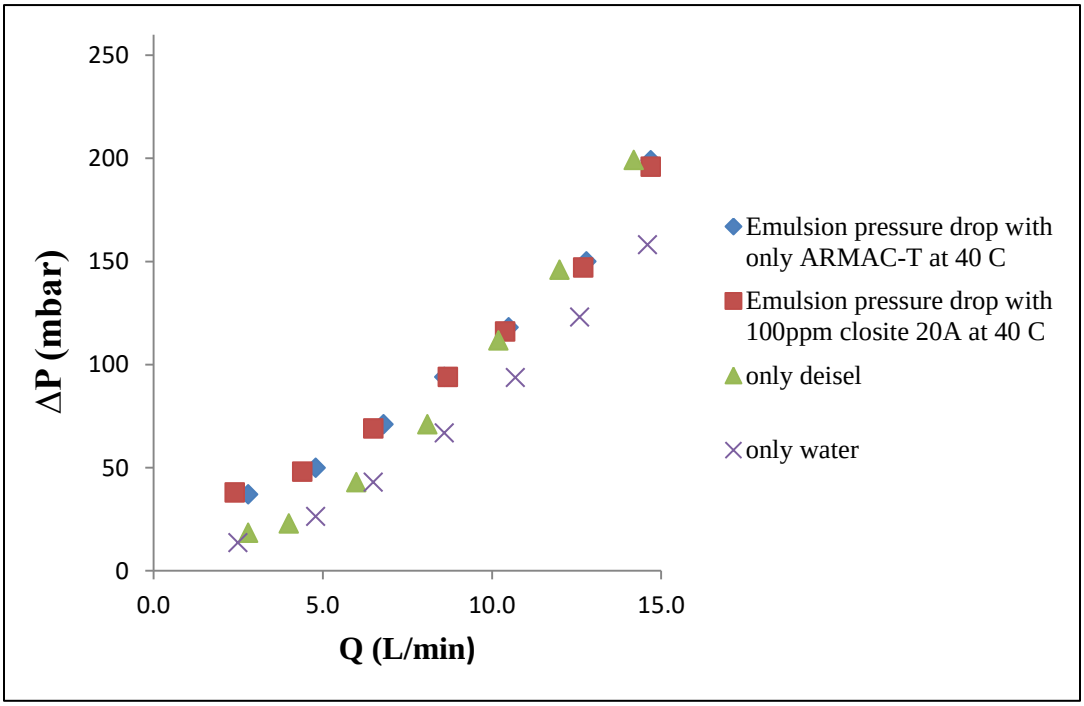


Figure 4-46: The 100ppm cloisite 20A effect at 40 °C

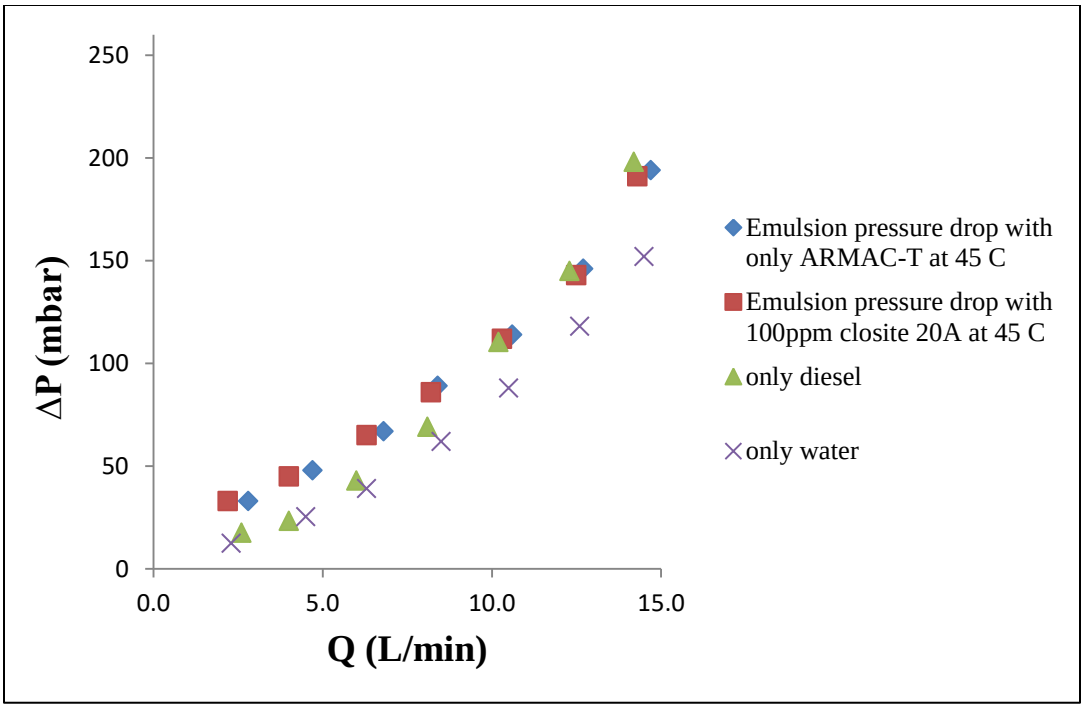


Figure 4-47: The 100ppm cloisite 20A effect at 45 °C

It can be seen from Figure 4-43 to Figure 4-47 that both cases Armact –T and Closite have similar results. At 40 C some differences can be seen. However, at high flow rate all are the same and even similar to pure diesel.

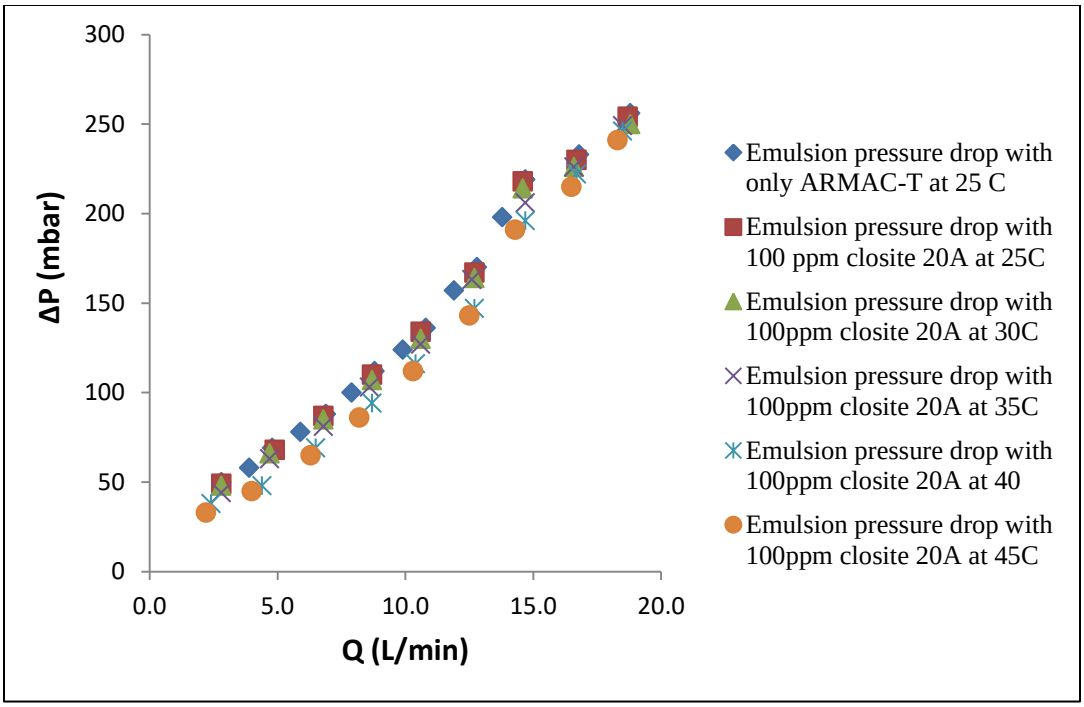


Figure 4-48: The effect of 100ppm closite 20A compared to the emulsion pressure drop with only ARMAC-T at 25 °C.

The figure shows that adding 100ppm of closite 20A to the emulsion at 25 °C has a very small effect but after increasing the temperature until 45 °C, the decrease in the pressure drop can be more effective. Here we can also notice that the same previous phenomena in which the pressure drop starts to decrease at high flow rate. To present the influence of the temperature in more clear way the percentage of deviation between the pressure drops at any temperature is compared with that at 25 C first to the emulsion with only the emulsifier agent and second for the emulsion after adding 100ppm closite 20A. The percentage of pressure drop reduction is defined as follows:

$$div\ \% = \frac{\Delta P_{with\ only\ ARMAC-T@25} - \Delta P_{@T}}{\Delta P_{with\ only\ ARMAC-T@25}} \times 100\%$$

Where

$\Delta P_{@T}$ ≡ represent the pressure drop at any temperature from 30 to 45 °C.

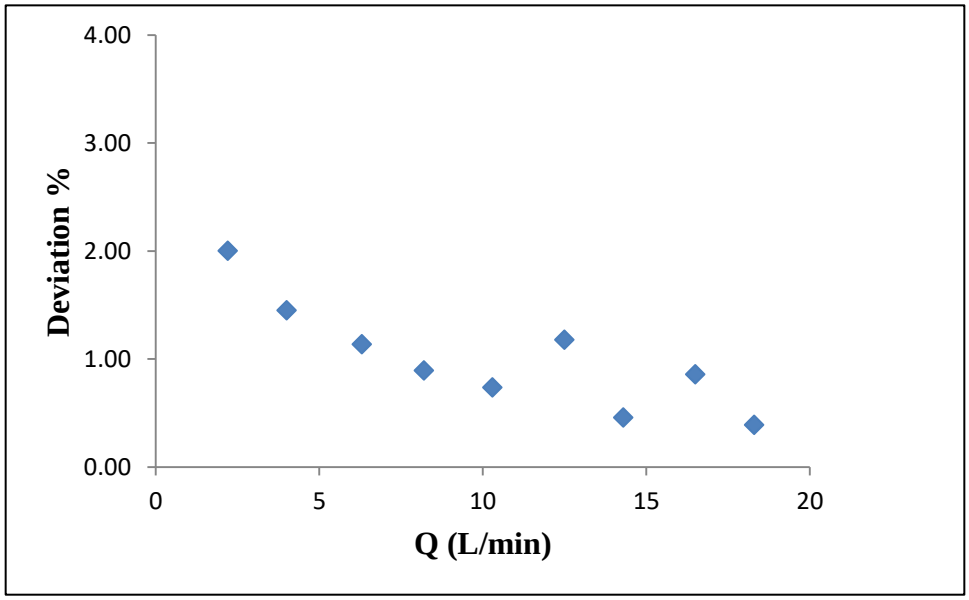


Figure 4-49: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 30 °C.

The figure shows that at low flow rates, the deviation is near to 2% and after increasing the flow rate the deviation start decreasing until it reached the lowest pressure drop deviation below 1%. This figure and the rest of deviation figures will clarify the phenomena mentioned earlier, where at high flow rates the pressure drop at different temperatures will get closer to the one at the lower temperature.

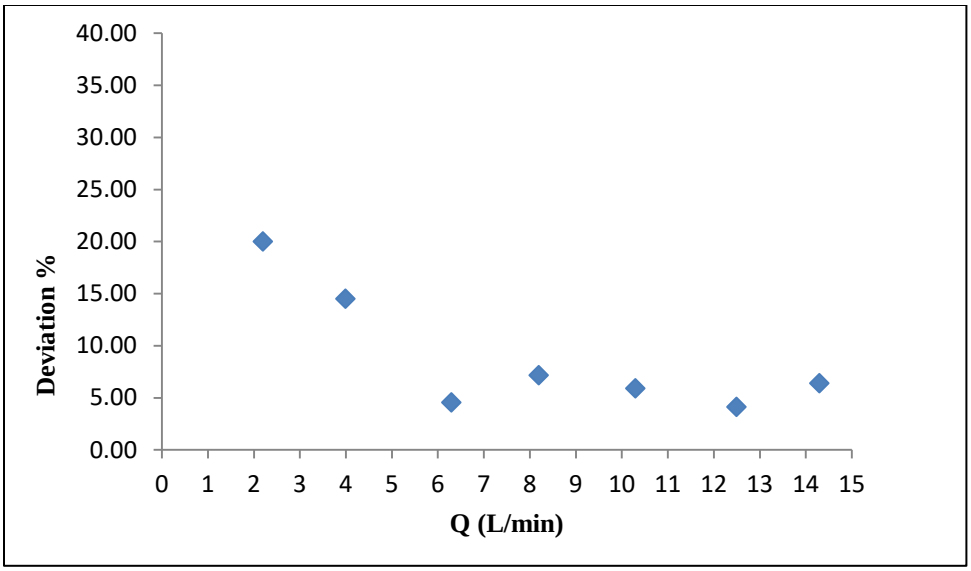


Figure 4-50: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 35 °C.

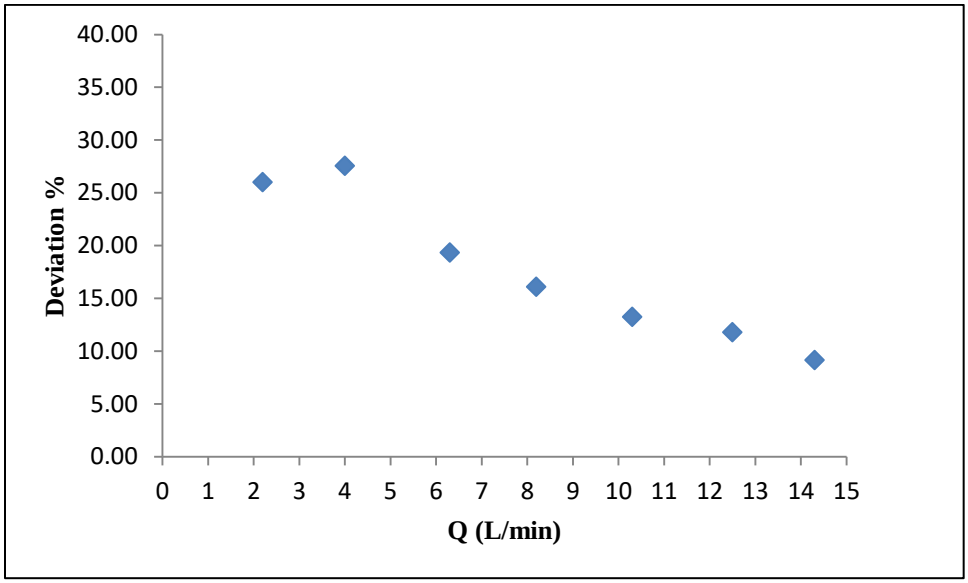


Figure 4-51: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 40 °C.

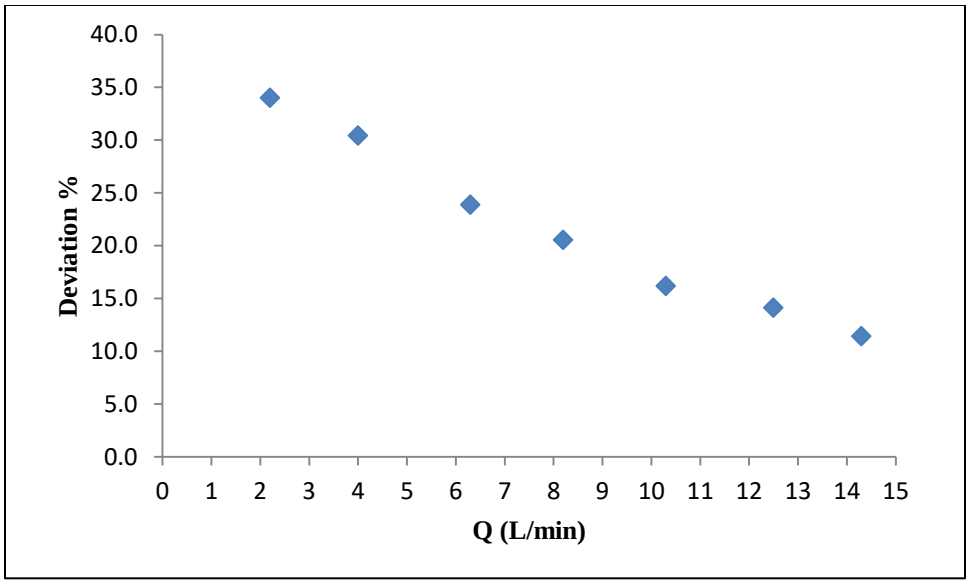


Figure 4-52: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion at 45 °C.

Here it is clear that the deviation of the higher temperatures (35, 40 and 45 °C) was increased until it reached about 10% reduction at the highest flow rate for 40 and 45 °C, where it is almost half of the case at 35 °C. This result can be attributed to the shear thinning effect of highly concentrated emulsions.

As mentioned before the deviation of the pressure drop of the emulsified emulsion at 25 °C and the emulsified emulsion with 100ppm closite 20A at different temperatures (25, 30, 35, 40 and 45 °C) are defined below:

$$div\,\% = \frac{\Delta P_{with\ only\ ARMAC-T@25} - \Delta P_{with\ 100ppm\ closite\ 20A@T}}{\Delta P_{with\ only\ ARMAC-T@25}} \times 100\%$$

Where

$\Delta P_{with\ 100ppm\ closite\ 20A@T}$= represent the pressure drop from 25 to 45 °C.

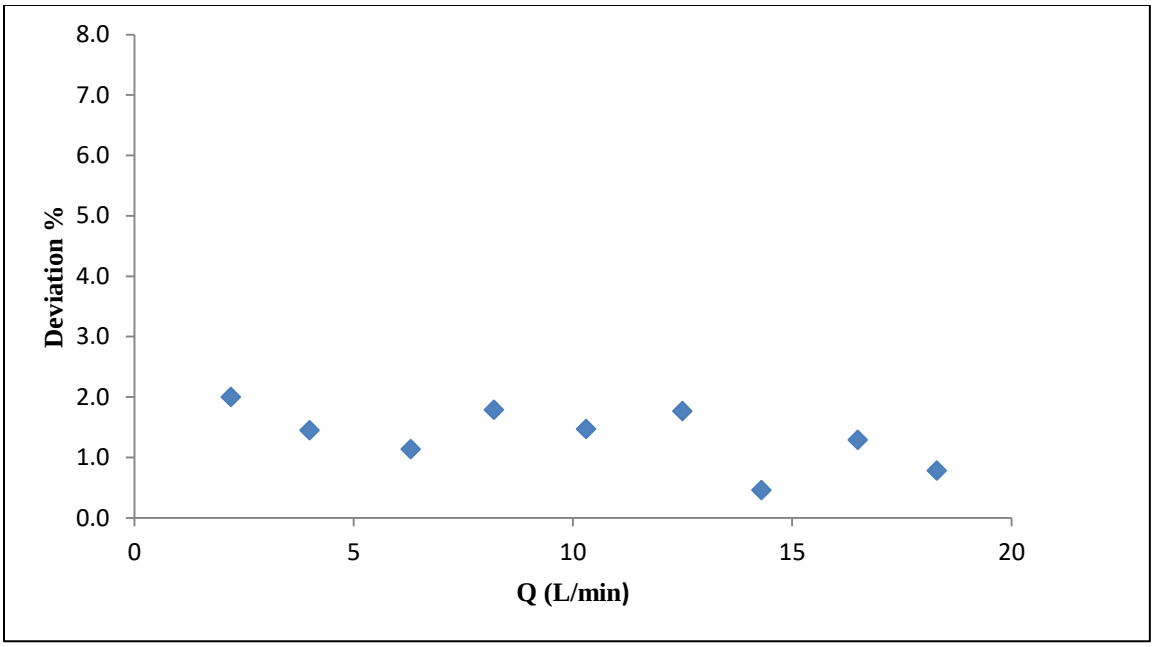


Figure 4-53: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 25 °C.

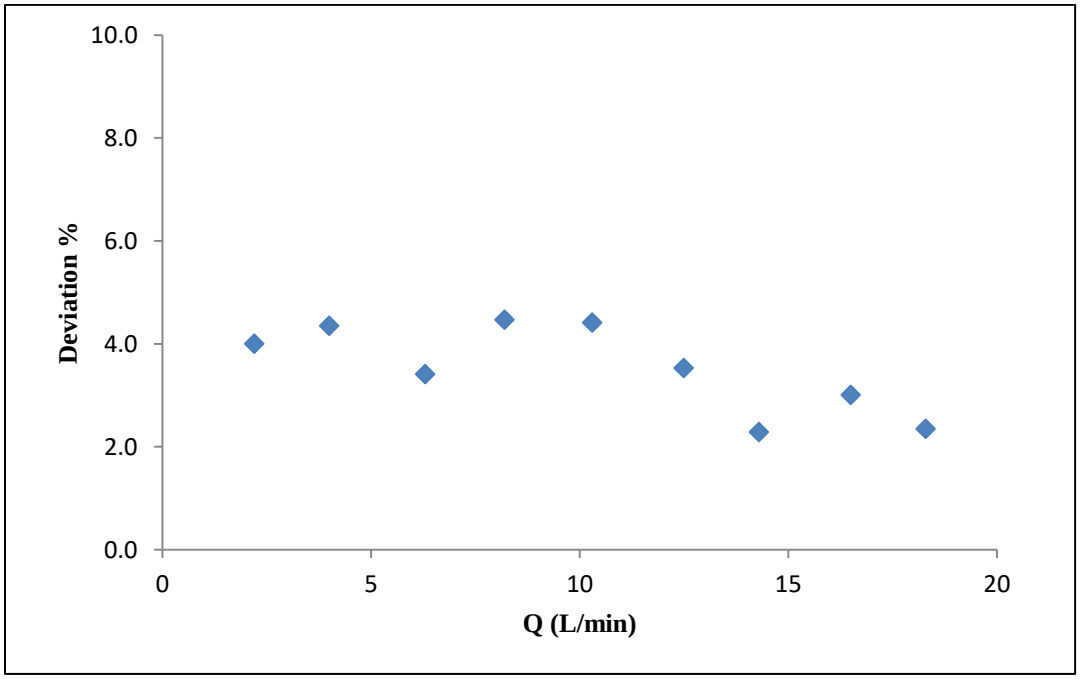


Figure 4-54: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 30 °C.

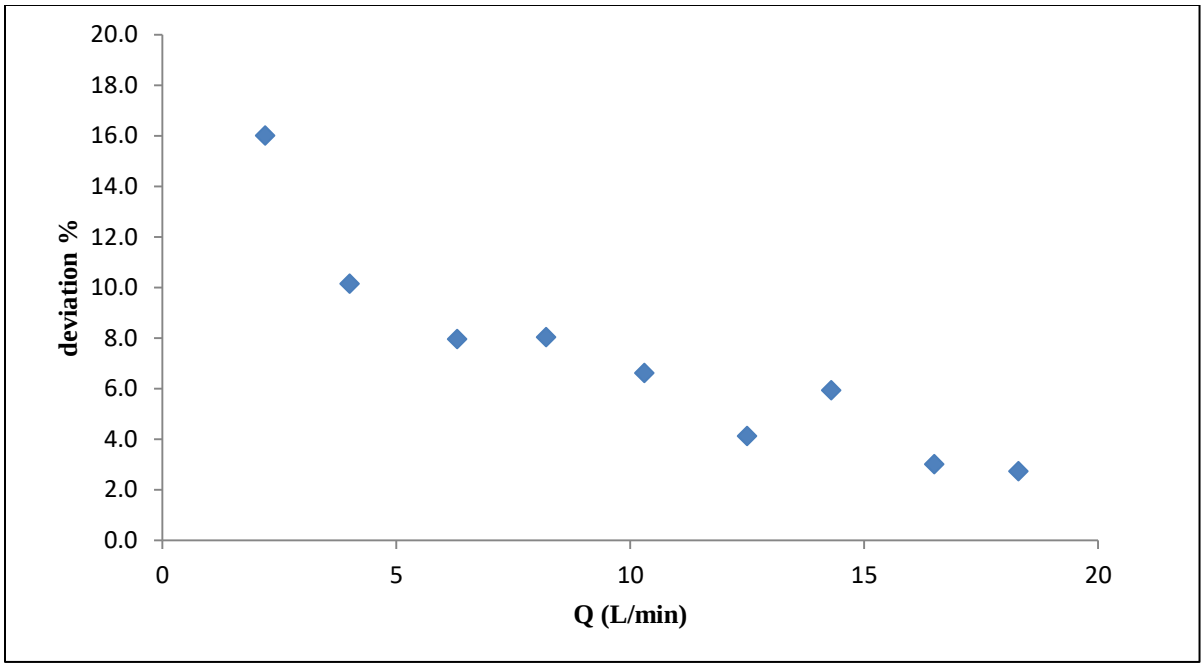


Figure 4-55: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 35 °C.

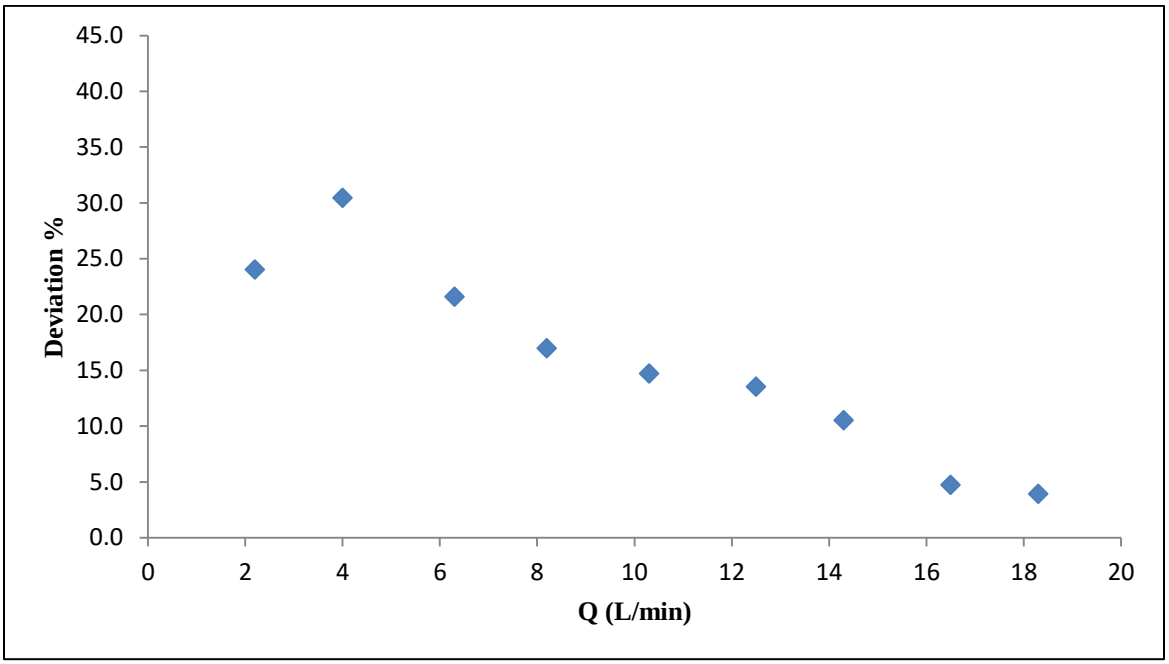


Figure 4-56: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 40 °C.

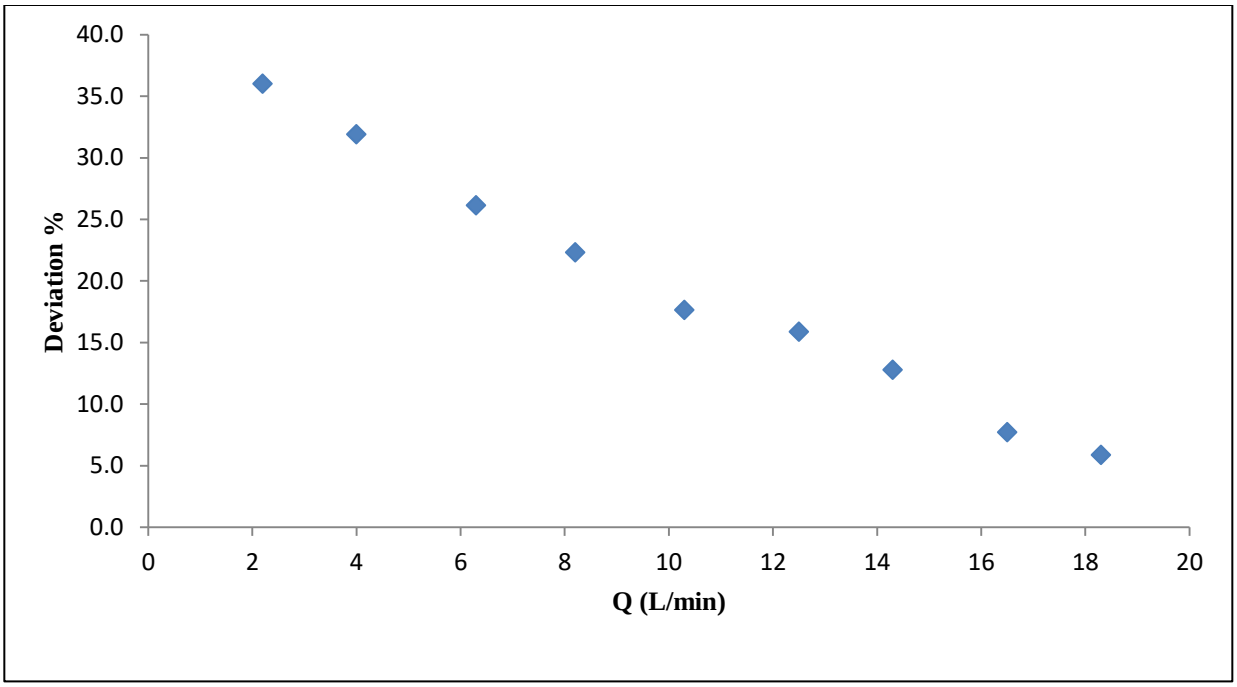


Figure 4-57: Pressure drop deviation between the emulsion with only ARMAC-T at 25 °C and the emulsified emulsion with 100ppm closite 20A at 45 °C.

The figure shows that the decrease in the pressure drop percentage is quite small for 25 and 30°C at high flow rates, where it then starts increasing after the temperature reaches 35 °C to reach 3% reduction in the pressure drop. The highest pressure drop percentage was at the 40 and 45°C (4 and 5 % respectively). The 100ppm closite 20A showed a small pressure drop reducer at the temperature of 45 °C where the percentage of reduction increased by 2% after adding 100ppm closite 20A.

Now, to clearify the effect of the 100ppm closite 20A, a deviation between the pressure drops of the emulsion with only ARMAC-T and with 100ppm must be done at the same temperature. This deviation can be defined as:

$$div\ \% = \frac{\Delta P_{with\ only\ ARMAC-T@same\ temprature} - \Delta P_{with\ 100ppm\ closite\ 20A@T}}{\Delta P_{with\ only\ ARMAC-T@same\ temprature}} \times 100\%$$

Where

$\Delta P_{with\ 100ppm\ closite\ 20A@T}$= represent the pressure drop from 25 to 45 °C.

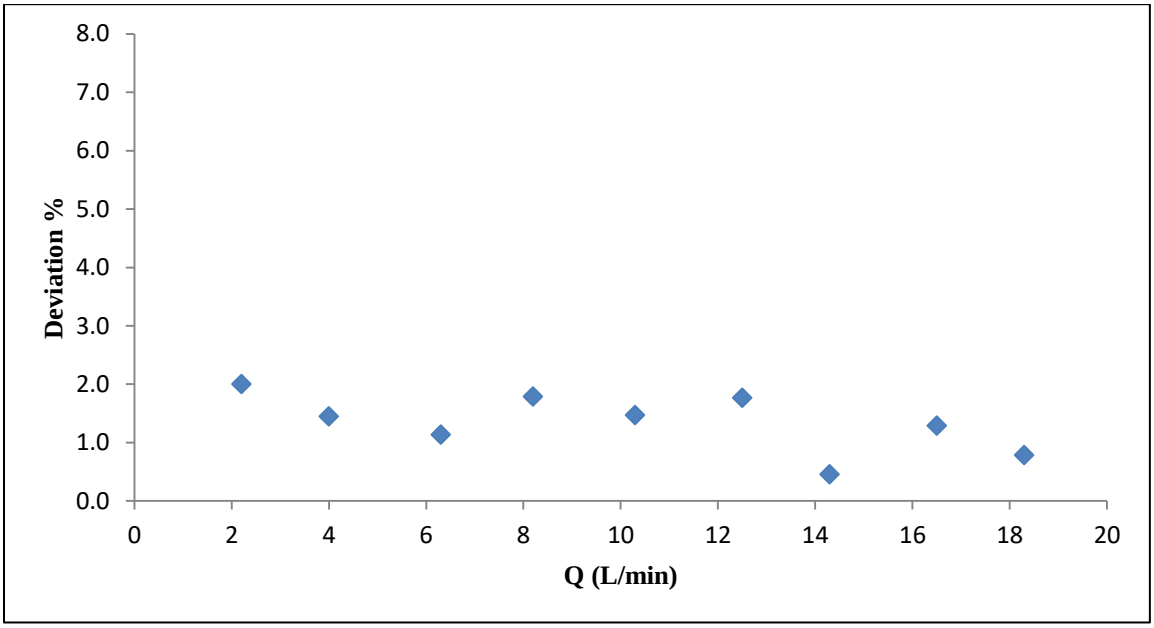


Figure 4-58: Deviation between the emulsion with only ARMAC-T and the emulsion with 100ppm closite 20A at 25 °C.

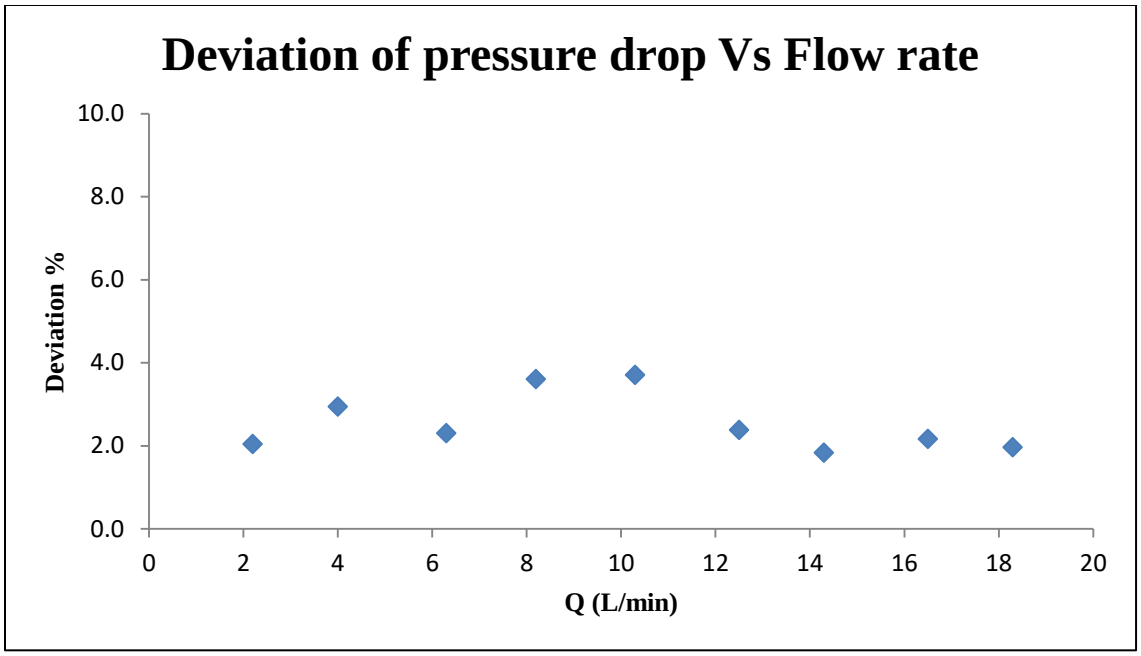


Figure 4-59: Percentage of deviation between the emulsion with only ARMAC-T and the emulsion with 100ppm closite 20A at 30 °C.

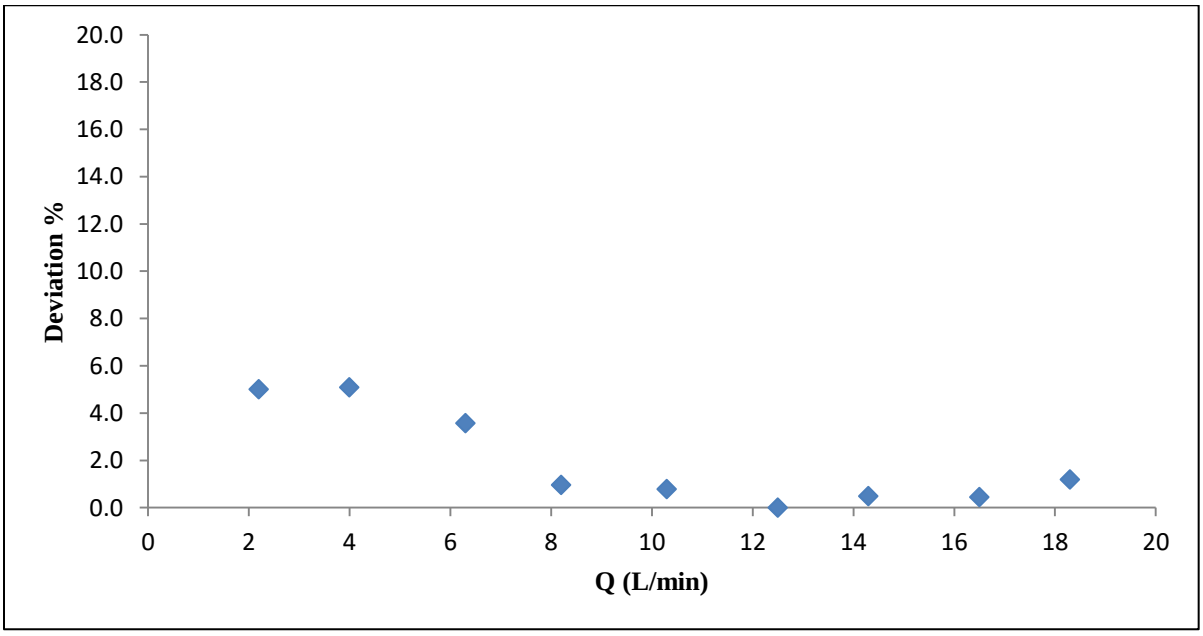


Figure 4-60: Percentage of deviation between the emulsion with only ARMAC-T and the emulsion with 100ppm closite 20A at 35 °C.

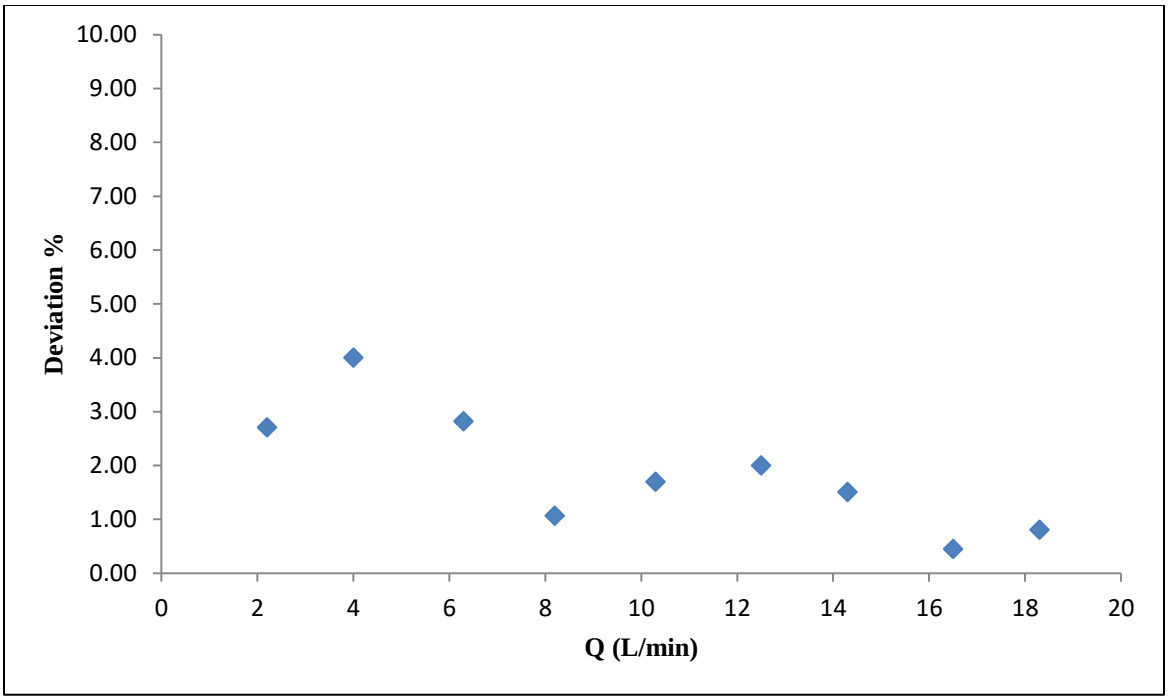


Figure 4-61: Percentage of deviation between the emulsion with only ARMAC-T and the emulsion with 100ppm closite 20A at 40 °C.

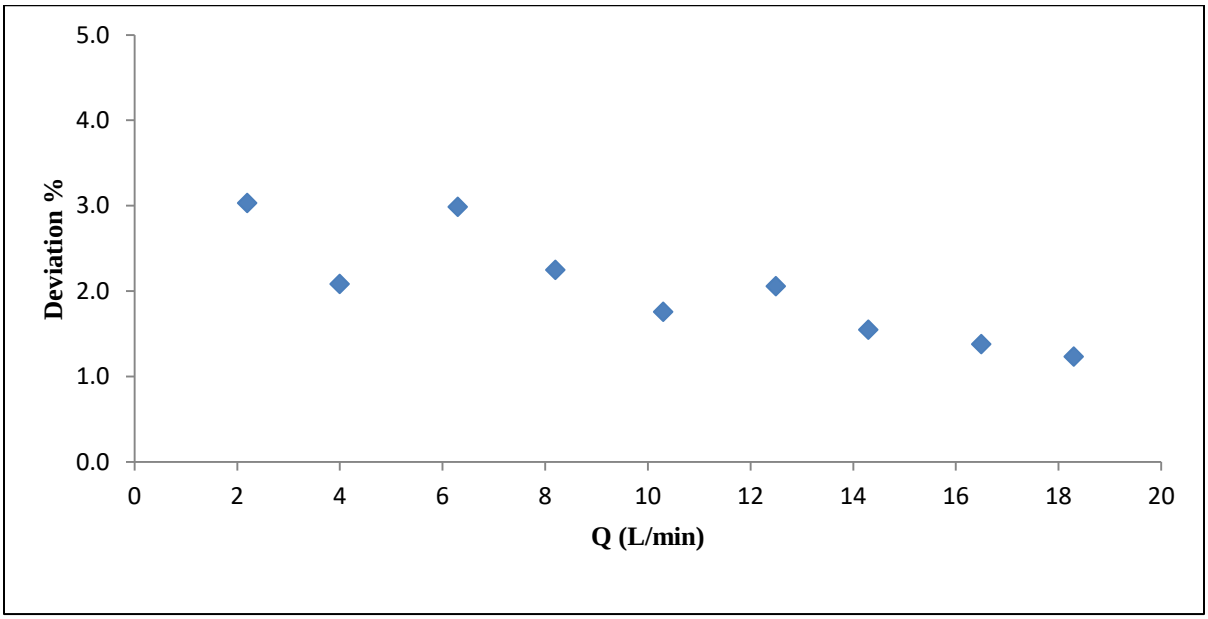


Figure 4-62: Percentage of deviation between the emulsion with only ARMAC-T and the emulsion with 100ppm closite 20A at 45 °C.

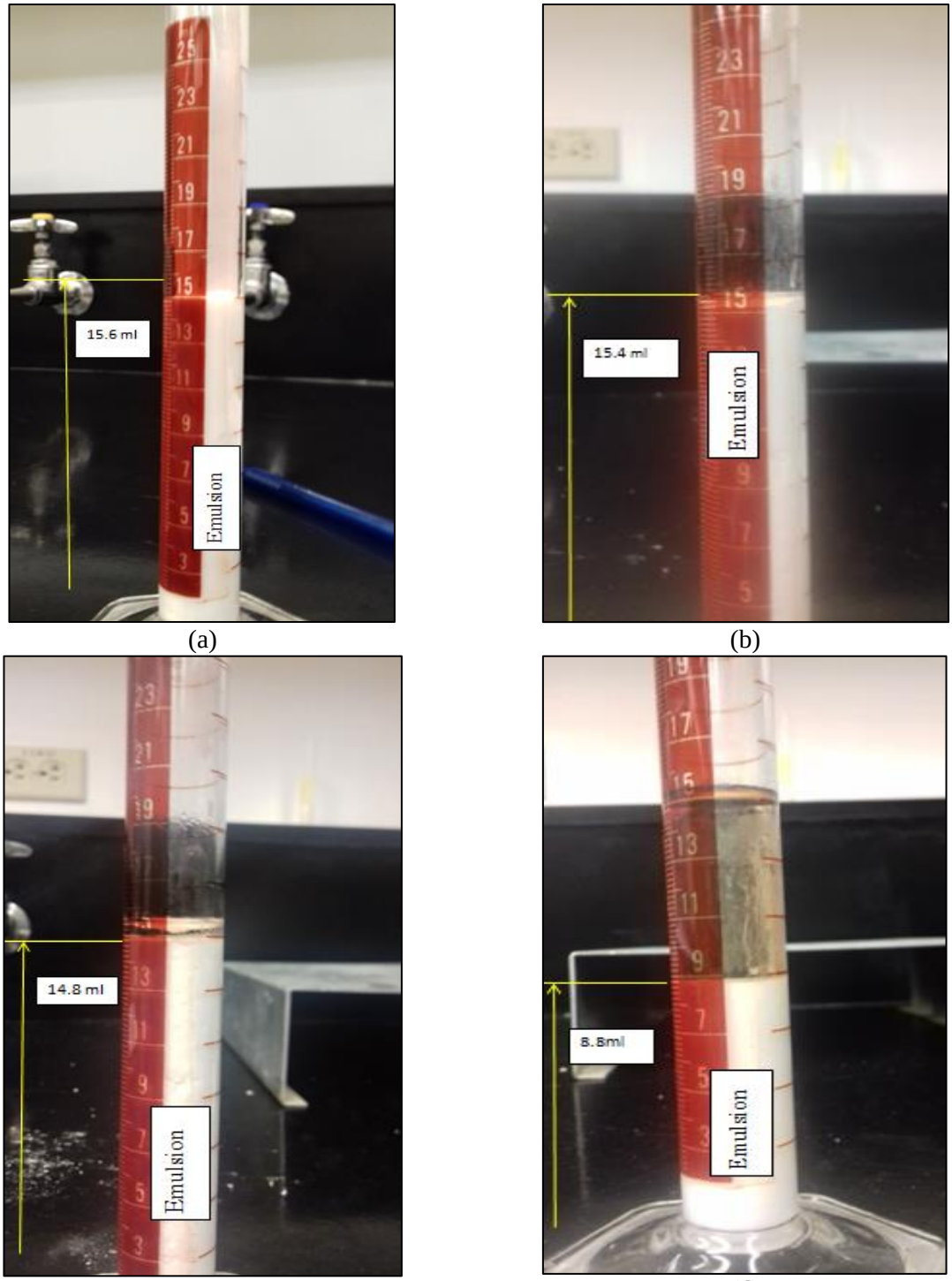
It is obvious that there is no significant effect of the 100ppm closite 20A at the same temperature. The reduction of the pressure drop at low flow rates are more than that at high flow rates. Moreover, increasing the temperature has a direct effect on the deviation. At high temperatures (40 and 45 °C), the maximum deviation can be seen to be about only 4% at low flow rates at 40 °C but at high flow rates the deviation is approximately the same for both temperatures.

Addition of 100ppm cloisite 20A to the w/o emulsion did not show significant change in the pressure drop at same temperature, higher concentration, namely, 1000ppm is also studied and explained in section 4.2.8.

4.2.8 The emulsion with emulsifier (ARMAC-T) and 1000ppm closite 20A:

The 1000ppm of cloisite 20A have been added gradually to the emulsion after it has been prepared. After that a sample of this emulsion was put inside an oven at 45 °C to check the stability of this emulsion:

The stability test for this emulsion is given below:



(a) (b)

(c) (d)

Figure 4-63: The emulsified emulsion +1000ppm closite 20A volume after: (a) mixing, (b) 2 hours, (c) 3 hours and (d) 20 hours:

The detailed variation of emulsion volume for 25 hours:

Table 4-9: The stability of the emulsified emulsion with 1000ppm closite 20A:

Time (hours)	Emulsion volume (ml)
0	15.6
2	15.4
3	14.8
10	12.4
15	10.6
20	8.8
22	8.8
25	8.8

The data in Table (4-14) shows that after 25 hours the volume of emulsion remaining was 8.8 ml, in another word only 56.4% of emulsion remains after 25 hours. But for our application, the targeted time is maximum 7 hours and for that time only less than 10% separated.

The figure below describes the behavior of this emulsion during 25 hours:

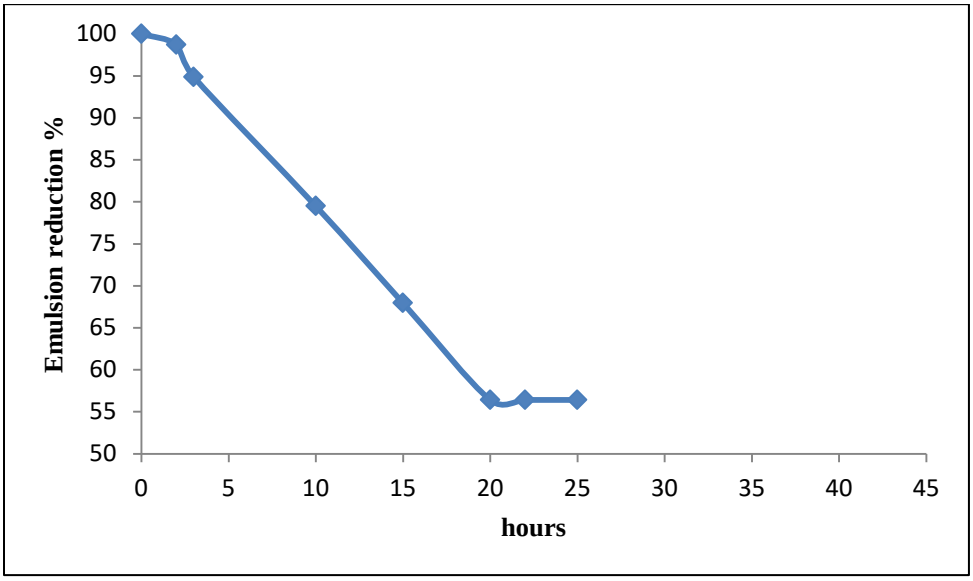
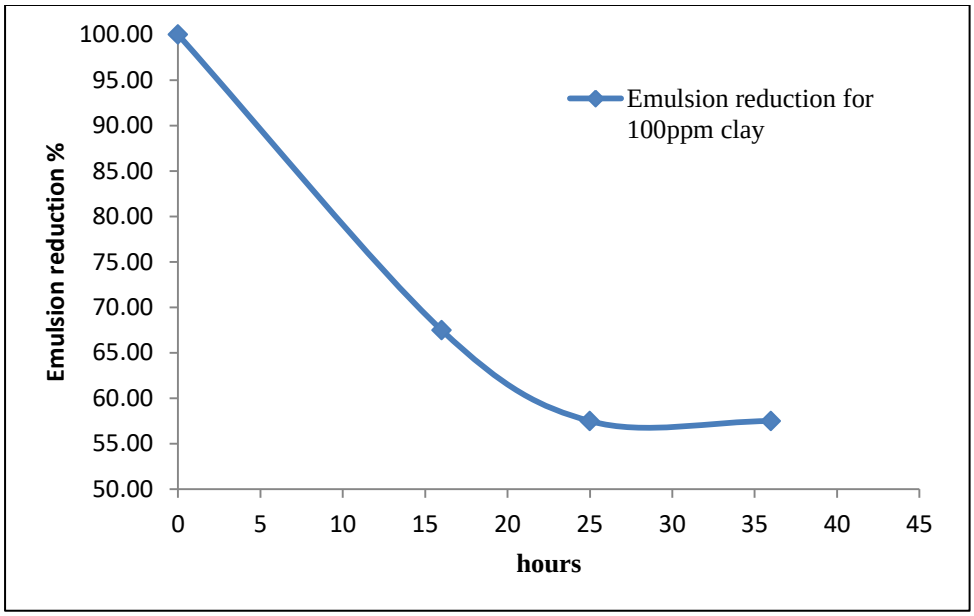


Figure 4-64: Emulsion volume through 25 hours for 1000 ppm clay

Figure 4-65 shows the stability curve at different clay concentration.

(a)



(b)

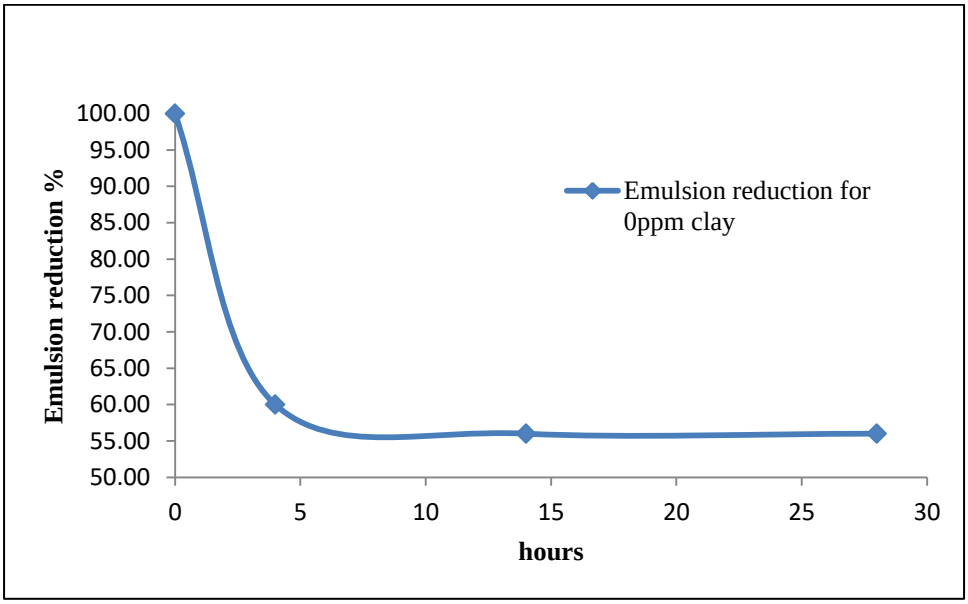


Figure 4-65: Shows the emulsion volume through: (a)40 hours and 100ppm clay (b) 28hours and 0 ppm clay

4.2.9 The rheology test results for emulsion with emulsifier agent (ARMAC-T)+1000ppm closite 20A:

Just after the batch was prepared a sample of the emulsion was held to do the rheological tests similar to previous cases. The steady shear and the density were obtained and the results are shown below:

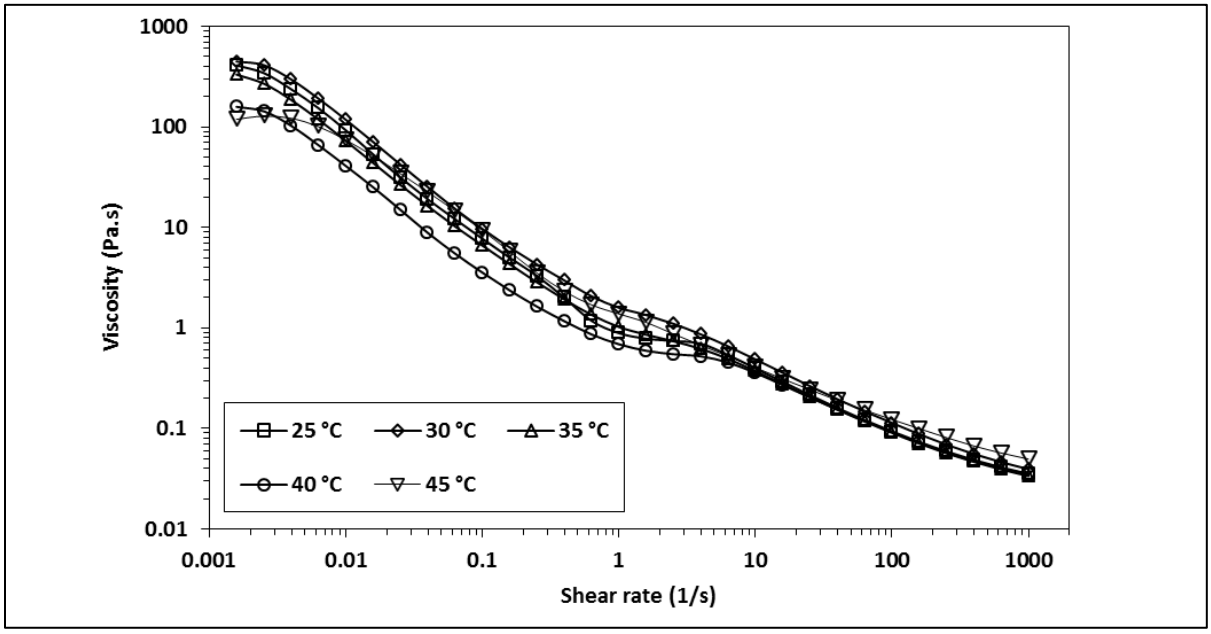


Figure 4-66: The steady viscosity with different temperatures

The viscosity at 25, 30, 35, 35 and 40 °C which is the temperature range of interest in this study is shown in figure 4-61. The pressure drop measurement results will be conducted at the same temperatures. The density and dynamic viscosity values at the interested emulsion temperature values are shown in Table (4-15).

Table 4-10: Density and the dynamic viscosity of emulsion at different temperatures

T (°C)	ρ, emulsion (Kg/m^3)	μ, emulsion (Pa.s)
25	913.73	0.03527
30	907.98	0.03930
35	904.42	0.03356
40	901.41	0.03503
45	899.07	0.03247

The pressure drop of all prepared surfactant-stabilized W/O emulsions were measured at different flow rates taken along 1.5m section of the stainless steel pipeline. All measurements were conducted at steady-state conditions. The emulsion temperature was changed from 25 to 45 °C.

3.2.9.1. The steady shear validation using Carreau fluid model:

Carreau fluid is a type of generalized Newtonian fluid where viscosity,μ_{eff} , depends upon the shear rate,γ, by the following equation:

$$\mu_{eff}(\gamma) = \mu_{inf} + (\mu_0 - \mu_{inf})(1 + (\varphi\gamma^2))^{\frac{n-1}{2}}$$

Where: μ_0 ,μ_{inf} , φ and n are material coefficients.

μ_0 = viscosity at zero shear rate (Pa.s)

μ_{inf} = viscosity at infinite shear rate (Pa.s)

φ = relaxation time (s)

n = power index.

At low shear rate ($\gamma \ll {}^1/_{\varphi}$) Carreau fluid behaves as a Newtonian fluid and at high shear rate ($\gamma \gg {}^1/_{\varphi}$) as a power-law fluid.

The model was first proposed by Pierre Carreau.

The model was applied to get the viscosity at the infinity and then compared between the data collected from the rheometer:

Table 4-11: The data resulted from Carreau model:

T	μ_0 (Pa.s)	μ_{inf} (Pa.s)	φ (s)	n	Transition index	R^2
25	0.107011	0.02239	0.0129568	0.3167	10.1469	0.9999
30	1.806	0.02182	0646	0.2855	1.687	0.9997
35	14.0723	0.02302	2.466	0.1127	0.3156	0.9998
40	77.4728	0.02305	5.978	0.0746	0.2017	0.9999
45	2.1052e9	0.02254	3.065e8	0.2041	0.0475	0.9999

Pressure drop measurement results for emulsion flow in pipe are presented below

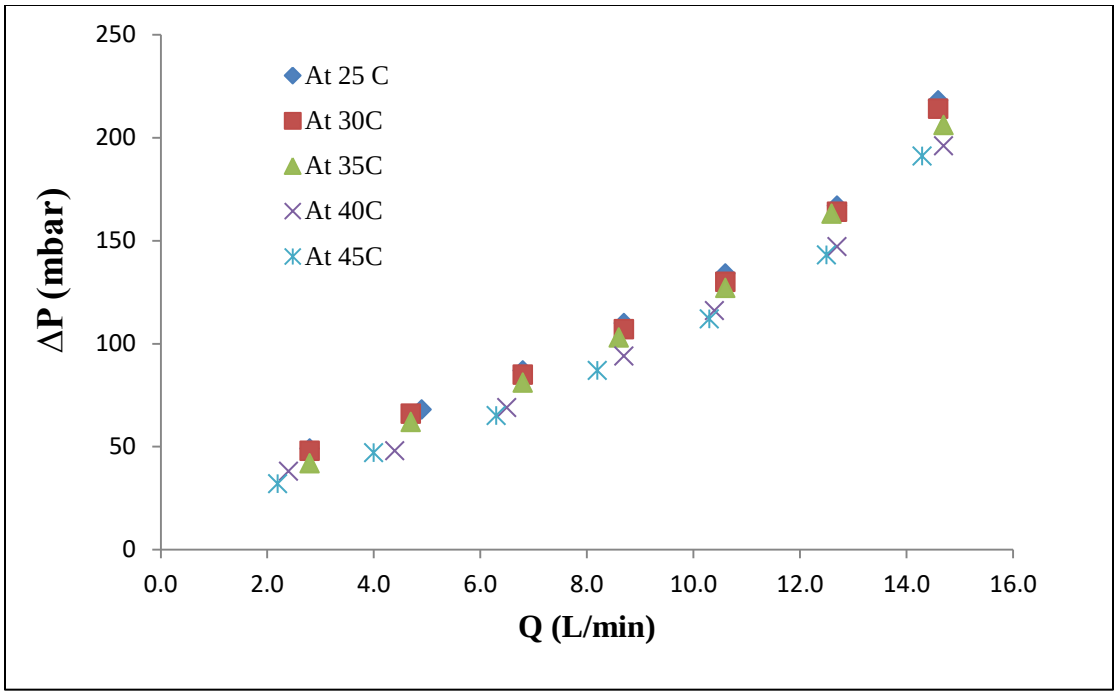


Figure 4-67: Pressure drop variation with the flow rate at different temperatures for emulsion with 1000ppm closite 20A.

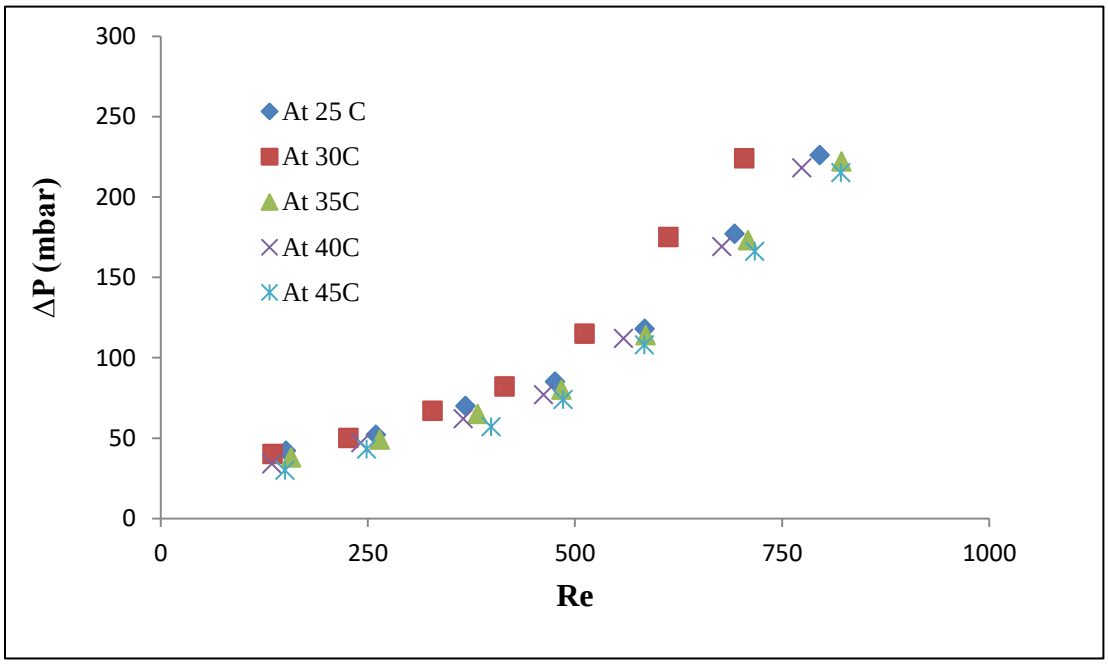


Figure 4-68: The pressure drop with Reynolds number variation at different temperatures for the emulsion with 1000ppm closite 20A

The figure above shows that the flow remains at the laminar level under all temperature ranges. The pressure drops increases with the increase of the flow rates. There is a closure of the pressure drops for the temperatures (25 to 45 °C) and this because of the effect of the 1000ppm on the viscosity. The difference between the viscosity at 25 °C and at 45 °C is quite low.

To investigate the effect of adding 1000ppm to the emulsion, the difference between the pressure drop of the emulsion with 100ppm closite 20A and the emulsion with 1000ppm closite 20A was presented as a percentage of deviation as shown in equation below.

$$div\,\% = \frac{\Delta P_{with\ 100ppm\ closite\ 20A@T} - \Delta P_{with\ 1000ppm\ closite\ 20A@same\ temp}}{\Delta P_{with\ only\ ARMAC-T@T}} \times 100\%$$

Where

$\Delta P_{with\ 1000ppm\ closite\ 20A@T}$= represent the pressure drop at same temperature.

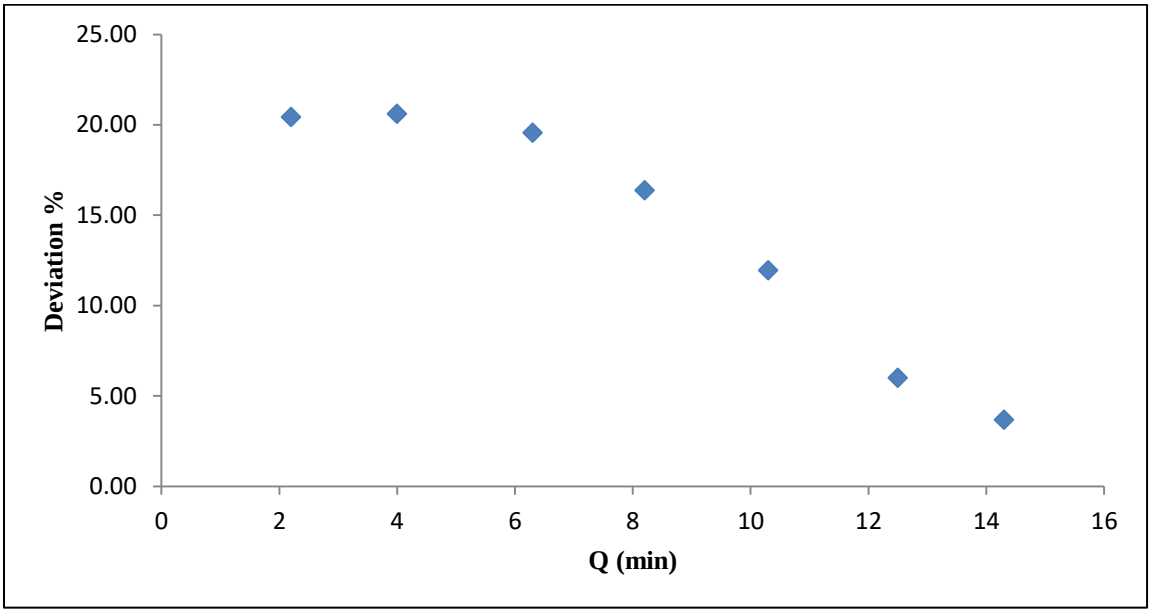


Figure 4-69:Deviation between the emulsion with 100ppm closite 20A and the emulsion with 1000ppm closite 20A at 25 °C.

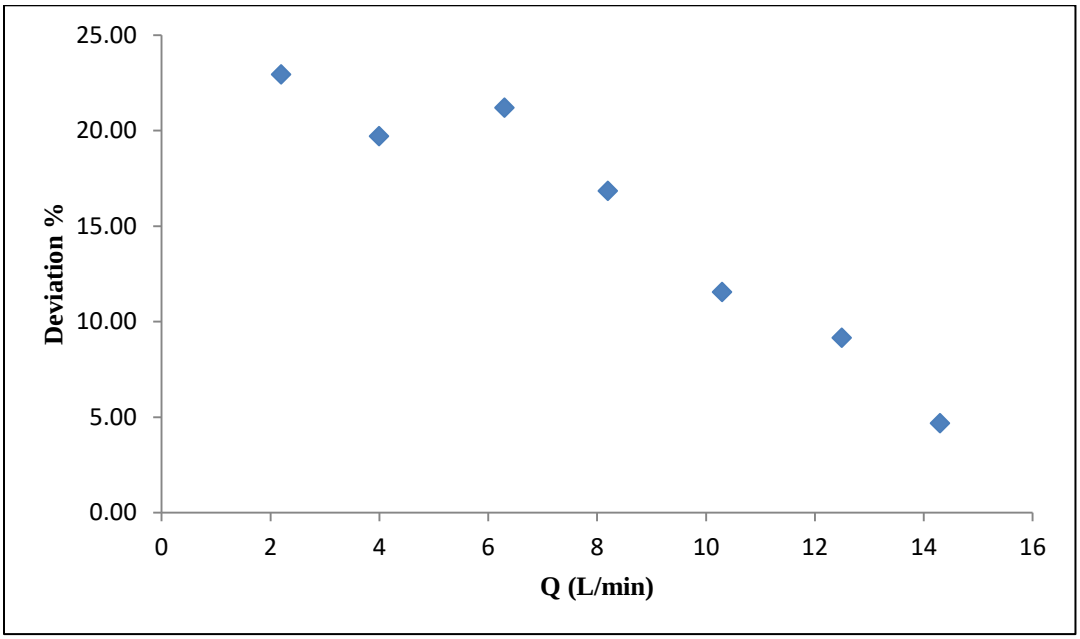


Figure 4-70: Deviation between the emulsion with 100ppm closite 20A and the emulsion with 1000ppm closite 20A at 30 °C.

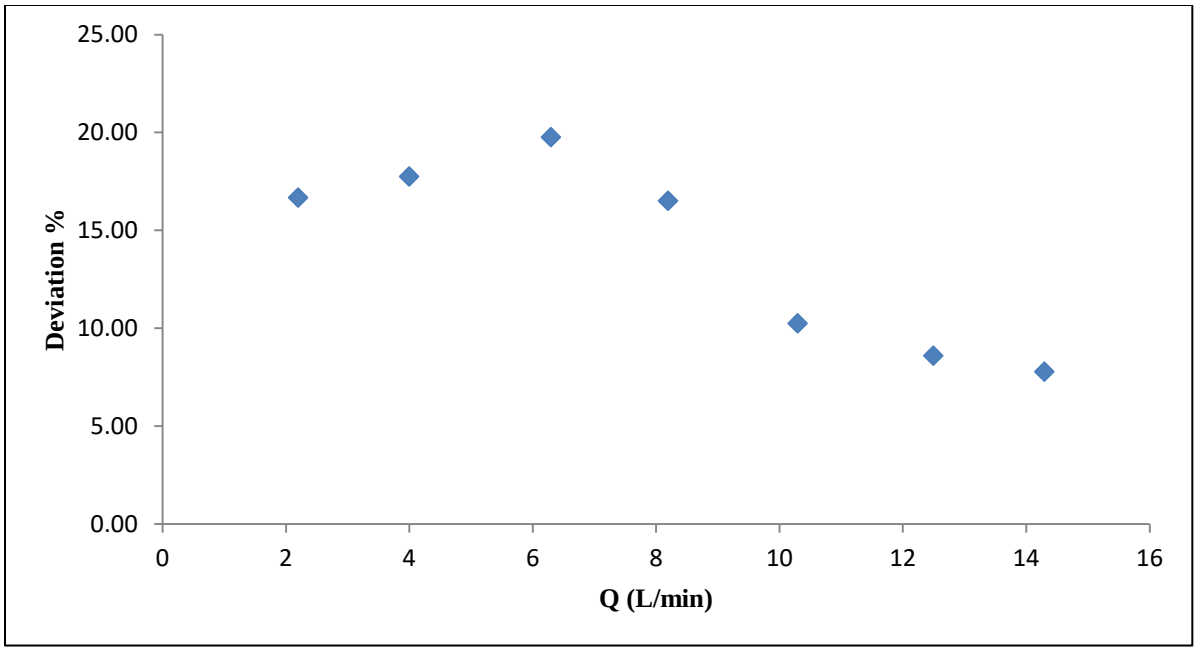


Figure 4-71: Deviation between the emulsion with 100ppm closite 20A and the emulsion with 1000ppm closite 20A at 35 °C.

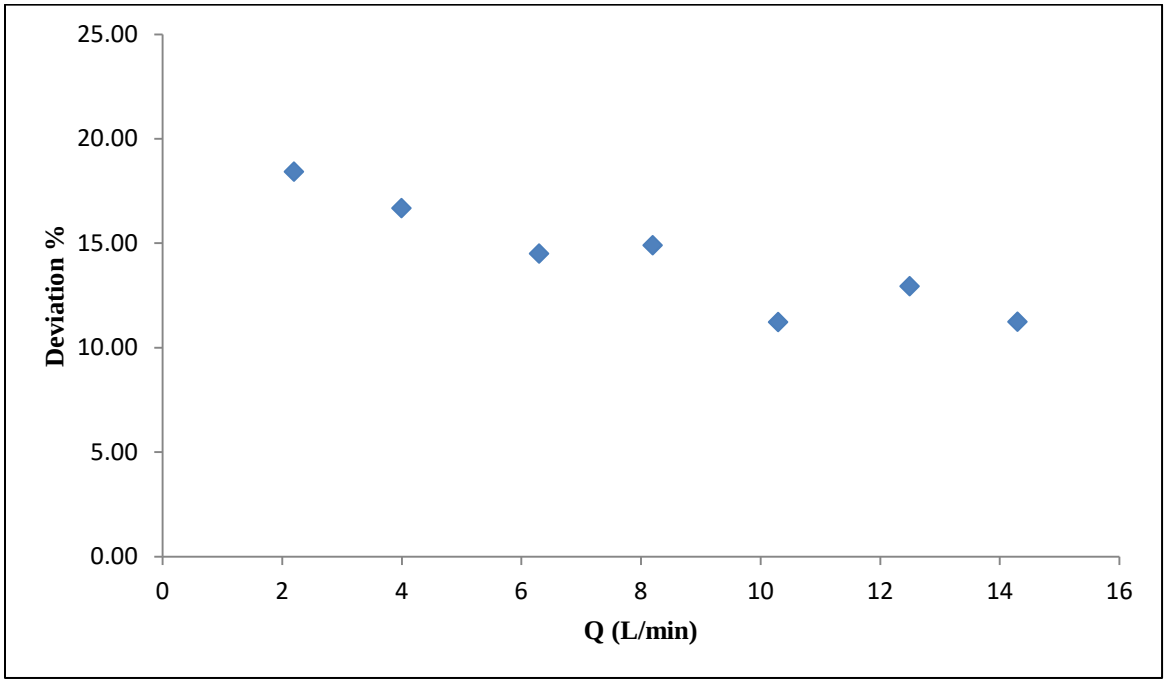


Figure 4-72: Deviation between the emulsion with 100ppm closite 20A and the emulsion with 1000ppm closite 20A at 40 °C.

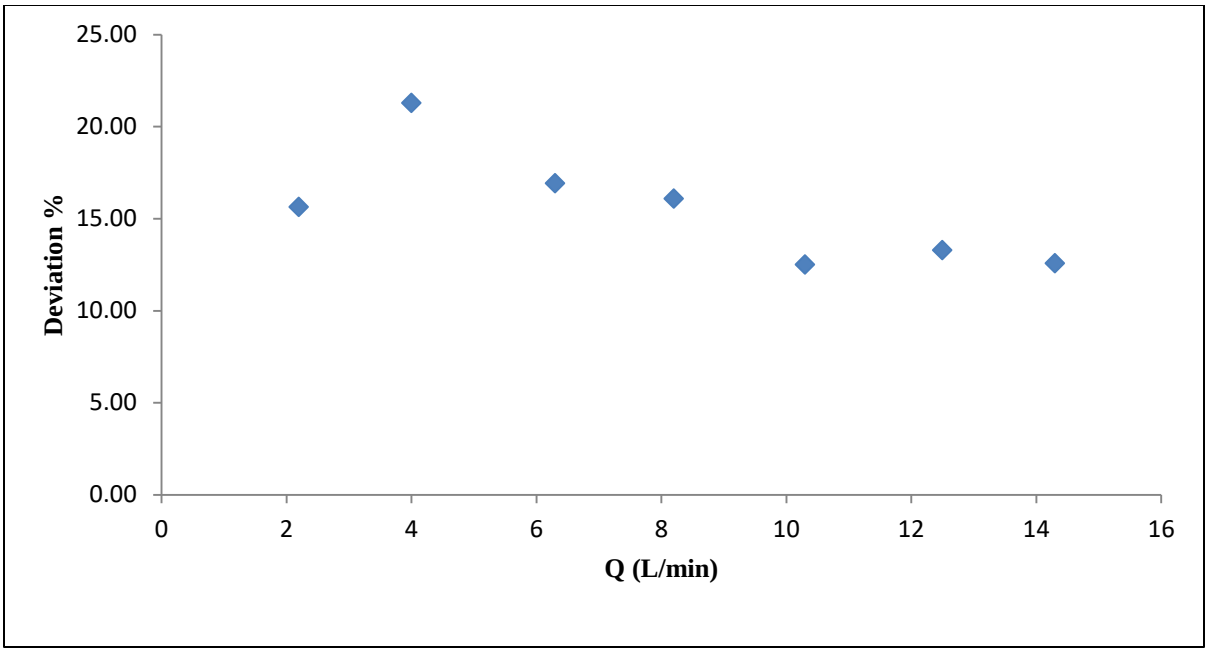
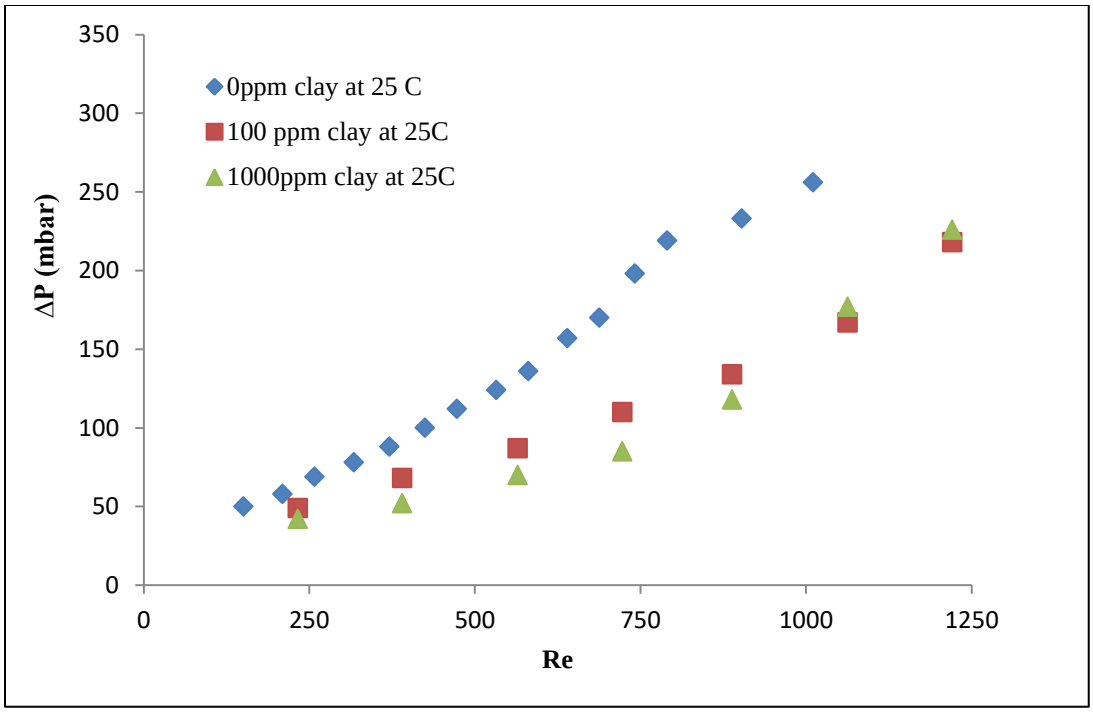


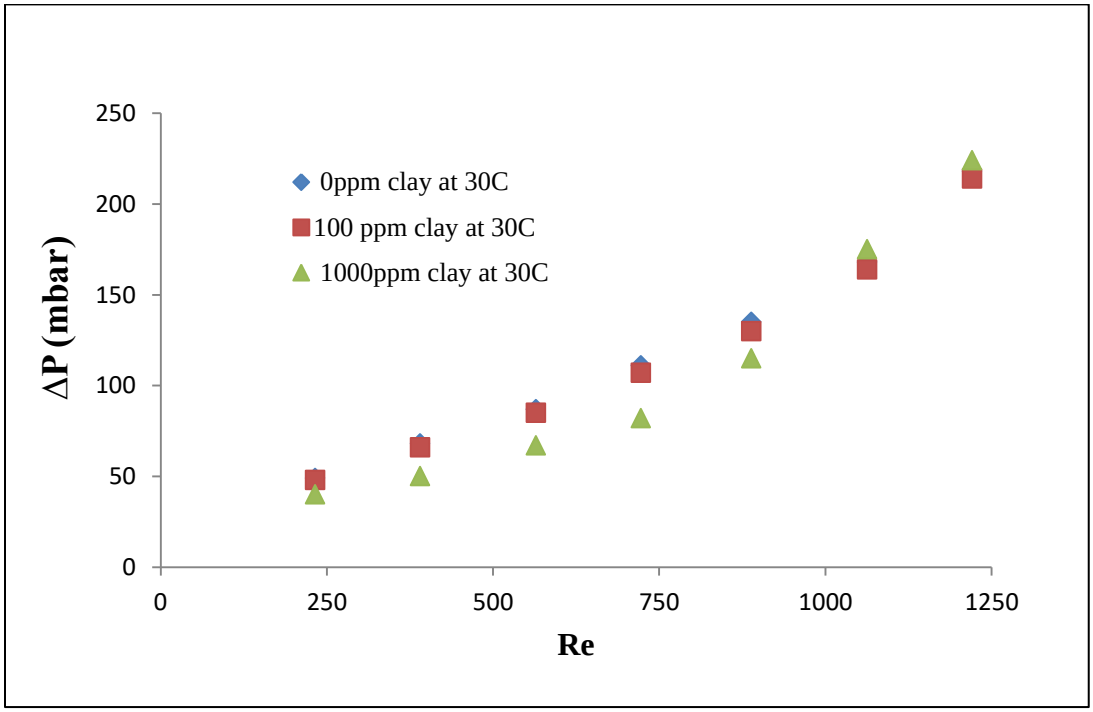
Figure 4-73: Deviation between the emulsion with 100ppm closite 20A and the emulsion with 1000ppm closite 20A at 45 °C.

The results show that adding 1000ppm closite 20A has an effect on the pressure drop especially at low flow rates. The pressure drop reduction starts from around 20% at 25 °C to reach around 15% reduction at the highest temperature (45 °C). Also, the reduction percentage will decrease by increasing the flow rate to reach around 14% reduction at 45 °C. It can also be realized that increasing the flow rate will result in a more flat trend between the two points at the lowest flow rate and the highest one.

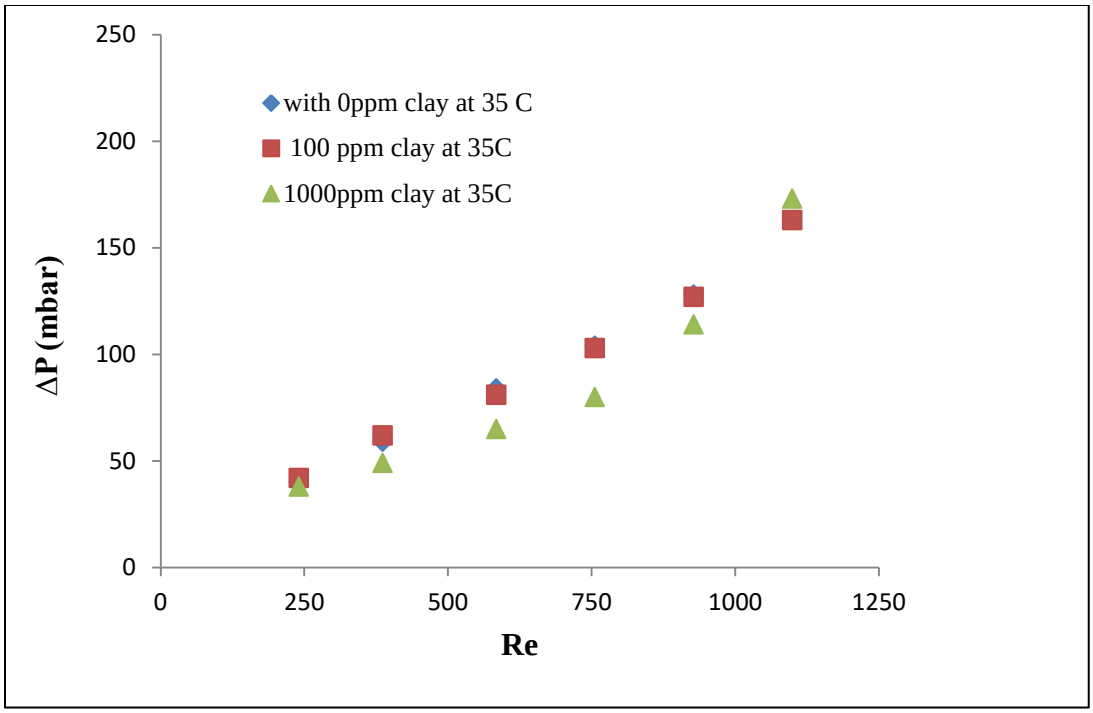
Figure 4-74 shows a comparison of the pressure drop at different clay concentration.


0ppm clay at 25 C
100 ppm clay at 25C
1000ppm clay at 25C
ΔP (mbar)
Re
0
50
100
150
200
250
300
350
0
250
500
750
1000
1250

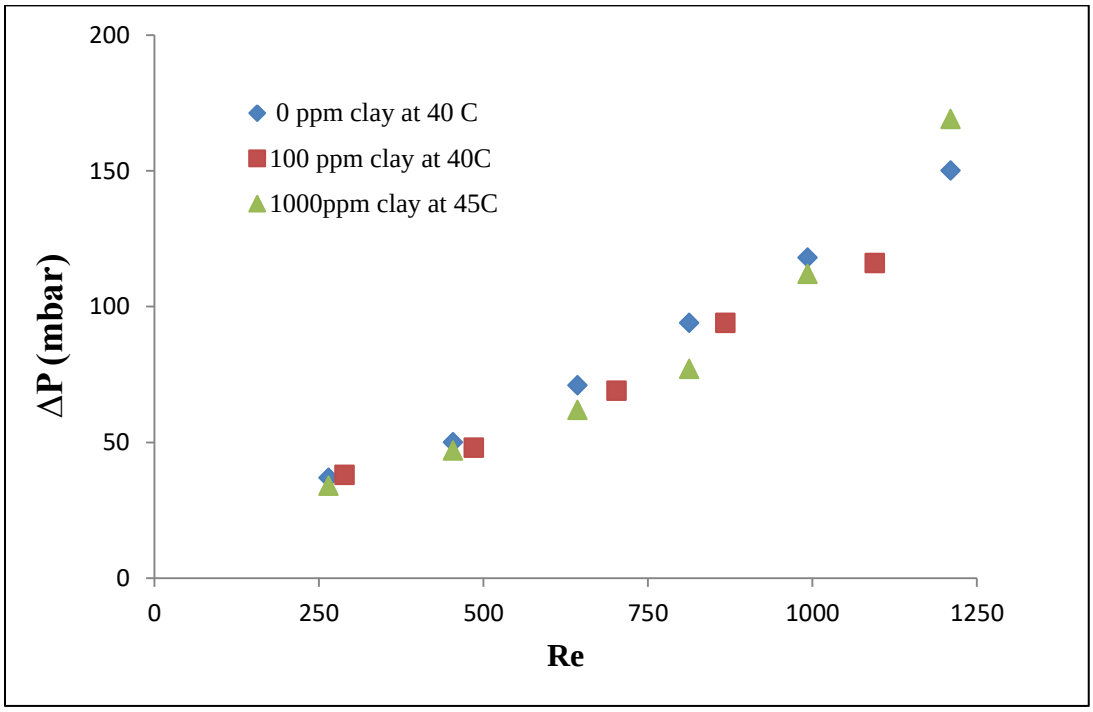
(a)


0ppm clay at 30C
100 ppm clay at 30C
1000ppm clay at 30C
ΔP (mbar)
Re
0
50
100
150
200
250
0
250
500
750
1000
1250

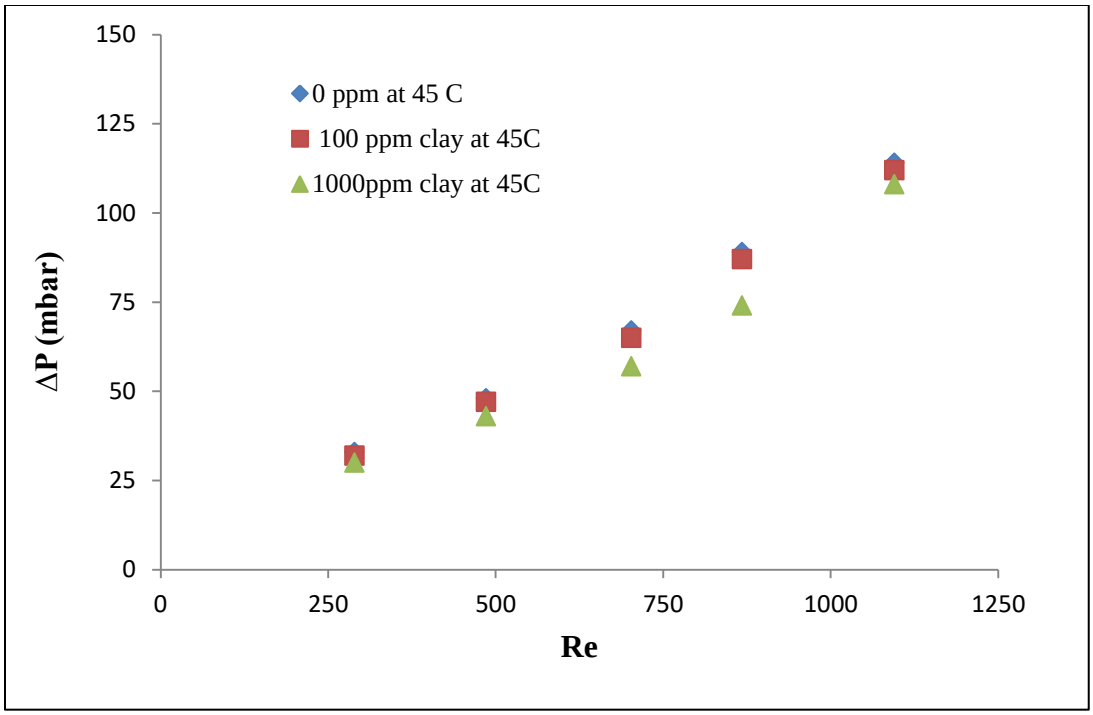
(b)


250
200
150
100
50
0
ΔP (mbar)
with 0ppm clay at 35 C
100 ppm clay at 35C
1000ppm clay at 35C
0
250
500
750
1000
1250
Re

(c)


200
150
100
50
0
ΔP (mbar)
0 ppm clay at 40 C
100 ppm clay at 40C
1000ppm clay at 45C
0
250
500
750
1000
1250
Re

(d)



(e)

Figure 4-74: Pressure drop variation with Reynolds number at different temperatures: a) 25°C, b) 30°C, c)35°C, d) 40°C and e) 45°C.

Figure 4-74 shows that the difference between the 0ppm clay and the 100ppm clay is small and it gets smaller with increasing the temperature. At high flow rated the pressure drop for the emulsion with 1000ppm clay will increase to reach approximately the pressure drop of the 100ppm.

CHAPTER 5

CONCLUSIONS

5.1 70/30, w/o emulsion:

Emulsion flow characteristics of surfactant-stabilized water-in-oil (W/O) emulsions at different temperatures and with and without oraganoclay (closite 20A) have been studied. The following conclusion can be drawn.

5.1.1 Temperature effect on the pressure drop (emulsion with only ARMAC-T)

Increasing the temperature leads to a decrease in the pressure drop of the emulsion and this is because of the breakage of the molecules bonds due the increasing in temperature. It is seems that at high flow rates the difference in the pressure drop at different temperatures get smaller. This result can be attributed to the shear thinning effect of highly concentrated emulsions.

5.1.2 The temperature effect on the pressure drop for the emulsified emulsion with 100ppm closite 20A:

Similar behavior occurs as the emulsified emulsion without adding cloisite. Also, It is seems that at high flow rates the pressure drop increases and it is clear that the pressure drop for each temperature gets closer to each other's at high flow rates. At the same temperature there is no effect of the cloisite at high flow rates (12 L/min and above), it seems that there is no difference between pumping any kind of the two emulsions and the pure diesel. Adding 100ppm of closite 20A to the emulsion at 25 °C has a small effect but after increasing the temperature until 45 °C, the decrease in the pressure drop can be effective. Here we can also notice the same previous

phenomena that the reduction in the pressure drop starts to decrease at high flow rate. The decrease in the pressure drop percentage (reduction) is quite small for 25 and 30°C at high flow rates, where it then starts increasing after the temperature reaches 35 °C to reach 7% reduction on the pressure drop. The highest pressure drop reduction was at the 40 and 45°C (10 and 15 % respectively). The 100ppm closite 20A showed a great pressure drop reducer at the temperature of 45 °C where the percentage of reduction increased by 5% after adding 100ppm closite 20A.

5.2 50/50, w/o emulsion:

5.2.1 The temperature effect on the pressure drop for the emulsified emulsion (only ARMAC-T)

Similar to 70/30, w/o emulsion, increasing the temperature leads to decrease the pressure drop. Moreover, at high flow rates the pressure drop increases. The pressure drop of the higher temperatures (35, 40 and 45 °C) showed an increase until it reached about 10% reduction at the highest flow rate for 40 and 45 °C, where it is the half for the 35 °C. This result can be attributed to the shear thinning effect of highly concentrated emulsions.

5.2.2 The temperature effect on the pressure drop for the emulsified emulsion with 100ppm closite 20A:

Here also the same behavior occurs similar to the emulsified emulsion without adding closite. It is also seems that at high flow rates the pressure drop increases . At the same temperature there is no effect of adding closite at high flow rates it seems that there is no difference between pumping any kind of the two emulsions and the pure diesel. The previous data showed that adding 100ppm of closite 20A to the emulsion at 25 °C has a very small effect but after increasing the temperature until 45 °C, the decrease in the pressure drop can be effective. Here

we can also notice the same previous phenomena that the pressure drop starts to increase at high flow rate (0 L/min and above). The decrease in the pressure drop percentage is quite small for 25 and 30°C at high flow rates, where it then starts increasing after the temperature reaches 35 °C to reach 3% reduction on the pressure drop. The highest pressure drop reduction was at the 40 and 45°C (4 and 5 % respectively). The 100ppm closite 20A showed a great pressure drop reducer at the temperature of 45 °C where the percentage of reduction increased by only 2% after adding 100ppm closite 20A.

5.2.3 The temperature effect on the pressure drop for the emulsified emulsion with 1000ppm closite 20A:

The specification of the emulsion flow with 1000ppm closite is quite different from that of 100ppm.

It should be noticed here that all the volume flow rates under consideration remain in the laminar region. The pressure drops increases with the increase of the flow rates. It can be noticed that the pressure drops profiles are getting closer for the temperatures (25 to 45 °C). This might be because of the effect of the 1000ppm on the viscosity. The difference between the viscosity at 25 °C and at 45 °C is quite low and this is because of the emulsion at 1000ppm became more condensing than 100ppm. Thus the temperature influence became less.

The comparison between the pressure drops of the 100ppm and the 1000ppm showed that the pressure drop after adding 1000ppm is less than that after adding 100ppm and there is a great reduction especially at low flow rates (2 to 8 L/min). The percentage of reduction starts from around 20% at 20 °C to reach around 15% at the highest temperature (45 °C). Also, the reduction percentage will decrease by increasing the flow rate to reach around 14% reduction at 45 °C at the highest flow rate.

5.2.4 Stability:

The stability tests of the two types of the emulsion (70/30 and 50/50) revealed that the stability of the 70/30 emulsion is much better than that of 50/50 with and without clay.

At different time durations the plots showed that after 50 hours an 80% of the 70/30 w/o emulsion with 0ppm clay remains emulsion with almost no separation while after 28 hours only 56% of the 50/50 remains. When comparing between the 70/30 and 50/50 w/o emulsions with 100ppm, it can be realized that the stability for the 70/30 is more to reach 75% to 57% at near the same time (48 hours to 40 hours).

Adding 1000ppm to the emulsion (50/50, w/o) showed a stability of 56% after 25 hours while it was the same for the same emulsion but with 0ppm clay.

5.2.5 Recommendations:

Based on the results presented in this study, the following recommendations are made to improve the quality of the data and to extend the scope of the research area:

1. Effect of different concentrations of the nonionic surfactant on the rheological and pressure drop should be considered.
2. Larger pump should installed to study the effect of organoclays on the pressure drop variation in turbulent region not only in the laminar region.
3. Vertical configuration should be considered since the density showed variable behavior which will influence the gravitational pressure drop.
4. Modify the loop temperature control to stabilize the temperature readings.

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